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300 MHz COMMUNICATIONS SURVEY OF THE LOS ANGELES AREA

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MARCH 1979

FINAL REPORT

Transportation
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16. Abstract

The study was conducted to determine the suitability of utilizing the 800-900 MHz band as the primary carrier of digital data communications pertaining primarily to the Multi-User AVM program. The study and investigation involved both analytical study and field testing of 800 MHz equipment in an urban environment. The city of Los Angeles, which will serve as the test bed for the Multi-User AVM program, was chosen as the test area. The field testing involved usage of a test vehicle, communication equipment, both on the vehicle and at the base station, and data acquisition equipment. Testing was conducted on specified test routes and wide area segments in the city of Los Angeles. Results on the area coverage, large and small scale signal variations, message error mechanisms, antenna polarizations, usage of different base station sites, usage of different baud rates, and comparison with model predictions were obtained.

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PREFACE

During the first half of 1978, as part of the Multi-User Automatic Vehicle Monitoring (AVM) Program, Contract DOT-TSC-1237, Gould Information Identification Inc. of Fort Worth, Texas, conducted a survey to determine the suitability of utilizing the 800-900 MHz band as the primary carrier of digital communication data pertaining to the Multi-User AVM Program. Testing was conducted on the six selected routes of the Southern California Rapid Transit District (SCRTD) and specified wide area segments in the city of Los Angeles. The AVM system is being developed for the Urban Mass Transportation Administration by Gould under Contract DOT-TSC-1237 to the U.S. Department of Transportation, Research and Special Programs Administration, the Transportation Systems Center.

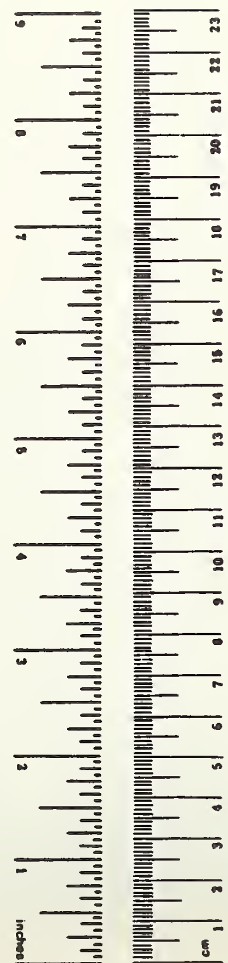
A large number of Gould personnel contributed to the success of this program. Particular acknowledgement is given to S. Franklin, F. Heathcock, R. Hajovsky and R. McLamb, who were involved in conducting the survey and data processing. A. Balaram and R. Hajovsky provided the needed support in the data analyses and documentation.

Special acknowledgement is given to B. Blood, the Transportation System Center's Project Monitor, B. Kliem, Project Engineer, and B. Wade, Radio Engineer, DOT-TSC.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

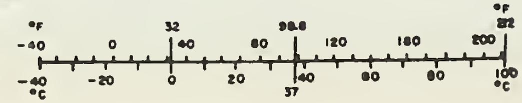


TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION 1

INTRODUCTION

1.1 Background

The purpose of the 800 MHz Study was to determine the suitability of utilizing the 800-900 MHz band as the primary carrier of digital data communications pertaining primarily to the Multi-User Automatic Vehicle Monitoring (AVM) program being conducted by Gould Information Identification Inc. (GI^3) for the U.S. Department of Transportation, Research and Special Programs Administration, Transportation Systems Center, under Contract DOT-TSC-1237. The results of this investigation appear to be significant to other applications of digital communications.

The primary reasons for exploring the possiblities of utilizing the 800-900 MHz band include (1) present limited availability of radio spectra in the public service and safety areas, and (2) an increasing demand for digital data communications by businesses in those areas.

The study and investigation involved both analytical study and field testing of 800 MHz equipment in an urban environment. The city of Los Angeles was selected as the test area, since it will be the site of the Multi-User AVM experiment in 1979-1980. AVM systems involve the transmission of digital data between one or more base stations and mobile units, which may operate either on a fixed-route or on a random-route basis. AVM digital data transmissions are potentially very susceptible to the effects of shadowing and multipath fading that are typically present in an urban environment. Shadow fading can be classified as a deterministic process involving the blockage of signals by terrain or large structures whose dimensions are typically many tens of wavelengths, resulting in a fairly uniform reduction in signal power. Multipath fading

can be classified as a more random process, resulting in the received signal being a net composite of multiple signals of different amplitudes and phases. Shadow fading produces the phenomenon of slow fade, whereas multipath fading results in what is referred to as fast fade. These phenomena of fading are especially detrimental to the transmission of digital data, resulting in bit errors which can produce a reduced throughput and/or message errors.

In the absence of any documentation concerning similar studies of the usability of the 800 MHz band in the Los Angeles area, the 800 MHz study became an integral part of the Multi-User AVM program. An experimental license for operation of a channel pair (808.4375 MHz) was granted to Gould by the FCC along with a waiver to transmit digital data over this voice band.

The study involved taking field measurements of such parameters as the noise level, the signal level, signal/noise ratio, throughput, coverage, and message errors. The effects of such variables as the transmit signal characteristics, receiver characteristics, antenna characteristics, line losses, propagation-path profiles, weather conditions, and the time of day were carefully documented in order to identify possible relationships that will provide more insight into the characteristics of this frequency band when used in an urban environment.

All data were taken in accordance with a test plan (Reference 1); however, supplementary tests were performed utilizing more than one base station site in order to gain more insight into the general relationship of fading to terrain and to supply coverage data for the Multi-User AVM program.

1.2 Test Description

The tests conducted simulated the operation of vehicles on both

transit and random routes. Tests involved operation of a mobile transceiver in an instrumented van and a fixed base station transceiver. The test routes consisted of:

- Nine test routes (Lines 2, 7, 26, 29, 41, 65, 83, 89, and 142 of the Southern California Rapid Transit District)
- A 30-square-mile area including the downtown Los Angeles Central Business District
- Selected freeways between Santa Monica on the west, West Covina on the east, Long Beach Harbor on the south, and the southern exposure of the San Gabriel Mountains on the north.

The total number of test runs taken on each route depended largely upon the results obtained. The tests were conducted in general in the "Survey Mode," i.e. at low sample rates. When marginal or poor results were obtained, sampling rates were increased to aid in characterization of the problems encountered.

At the start of each day, a "standard" calibrated test run was conducted on a short segment of roadway which was characterized by a signal-to-noise ratio (S/N) greater than 30 dB, negligible fading or interference, and line-of-sight operation to the base station. This "standard" test run served to verify the proper functioning of both mobile and base station equipment. Once this was completed, the regular test runs were conducted on the designated test path.

Prior to each test, all header details corresponding to the Run Number, Date, Start Time, Operating Mode, and Calibration Data were recorded by the test director on cassettes through the use of a set of keyboard entries to the on-board computer. Thereafter, the actual run was conducted in the survey mode, with the vehicle equipment automatically polling the base station as the vehicle progressed at regular in-

tervals of 50 feet. At each poll, the appropriate time-coincident data such as signal level, noise level, S/N ratio, throughput, and undetected message errors were determined through use of the vehicle instrumentation, and this information was recorded on the cassettes. At designated checkpoints, under specific guidance from the test director, data were also input by the test operator onto the cassetts through use of the keyboard.

The procedure for conducting the tests in problem areas was essentially the same as a normal run, the only difference being that a more detailed description of the environment condition was recorded. Test log sheets were also prepared in conjunction with each test run.

The tests mentioned above were subsequently performed through the use of four different base station sites, the appropriate data being collected and maintained separately and categorized for each base station.

After all the tests were completed and data recorded on the log sheets, the entire data base was brought to the Gould facilities at Fort Worth, Texas, for detailed analysis.

1.3 Equipment Description

The equipment involved in the testing program included:

- the test vehicle
- the communication equipment
- the data acquisition equipment.

The configuration of the 800 MHz test appears in Figure 1-1.

1.3.1 Test Vehicle

The test vehicle, shown in Figure 1-2, was a 1978 Winnebago Brave equipped with a 4 KVA auxilliary power unit to handle the power requirements of the Data Acquisition System (DAS) and the mobile communication equipment. The DAS consisted of a minicomputer, a cassette recorder, a printer/keyboard, a strip-chart recorder, and an odometer. The communi-

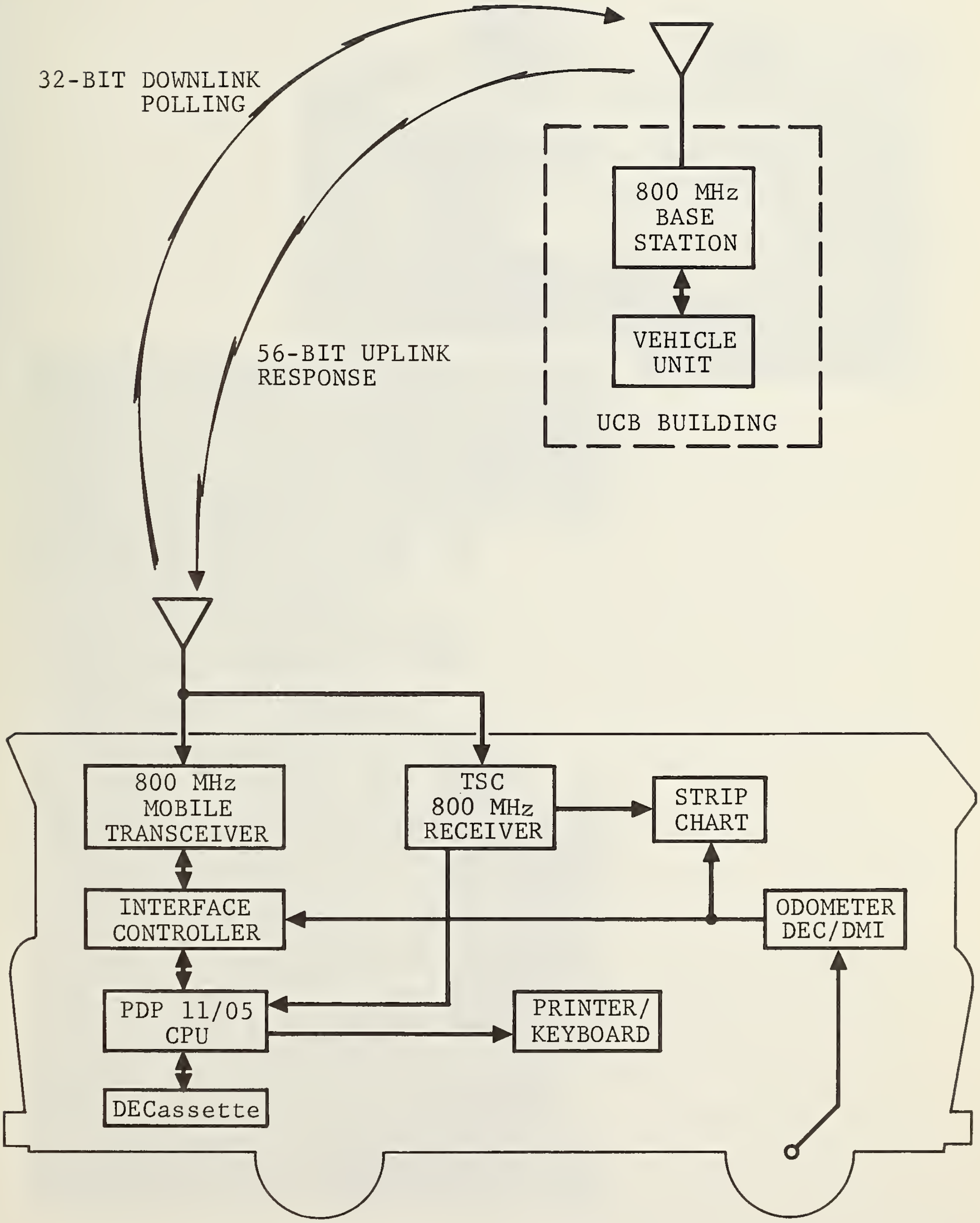


FIGURE 1-1 800 MHz TEST VEHICLE CONFIGURATION

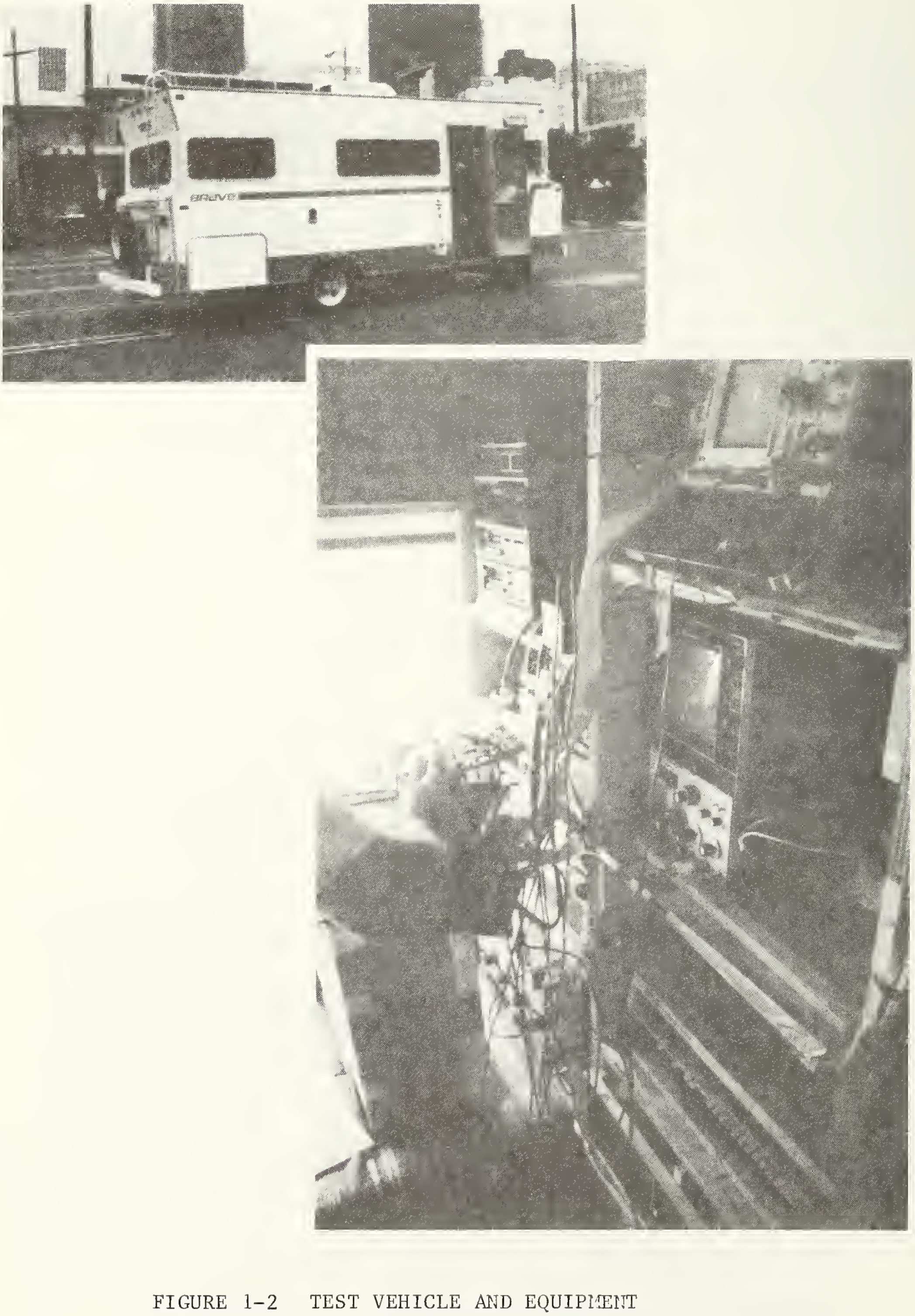


FIGURE 1-2 TEST VEHICLE AND EQUIPMENT

cation equipment consisted of an off-the-shelf mobile radio, a government-owned receiver, and a specially designed interface controller.

The vehicle was equipped with adequate power, air conditioning, and heat to accommodate all required equipment and personnel.

1.3.2 Communication Equipment

The communication system consisted of the communication equipment associated both with the base station and the vehicle. The vehicle unit operated as the interrogator (uplink) of the base station. The base station received, decoded, validated, reformatted, and retransmitted the uplink message back (downlink) to the vehicle unit. Thus, for testing purposes, the base station operated as a transponder, thereby allowing all testing to be accomplished without any test personnel at the base station site.

The communication equipment in the vehicle unit consisted of the mobile radio (a commercial FM transceiver operating in the 800-900 MHz range), the interface controller, and the receiver supplied by the Transportation Systems Center (TSC). The mobile radio interrogated the base station with digital data transmissions that simulated base-to vehicle messages. Different 32-bit messages generated pseudo-randomly by the minicomputer were coded in a bit-bit complement ($B-\bar{B}$) format with attendant preamble synchronization and postamble and transmitted to the base station using a mobile antenna of suitable configuration and polarization. In this way, transmissions were initiated in the vehicle minicomputer, implemented in a Radio Interface Module (RIM) card, and, after being FSK modulated and filtered, were fed into the microphone input of the mobile radio for transmission to the base station.

The TSC receiver was a special receiver belonging to TSC that was used on a previous TSC program to characterize a pulse ranging system.

The receiver provided a log output of signal strength and exhibited the required sensitivity. The TSC receiver was modified to make the data collected from this experiment viable in determining the suitability of the 800-900 MHz channel for digital operation. This modification consisted primarily of adjusting the IF bandwidth to correspond to those of the commercial radios (16 KHz) and adding a bandpass cavity filter at the receiver input.

The base station communication equipment consisted of a commercial 800 MHz base station, a commercial base station antenna, and an interface controller. Interrogations from the vehicle unit were received, demodulated, decoded, error filtered, reformatted, and transmitted as a 56-bit message back to the vehicle unit. Frequency shift keying was used, with the modulating frequency being shifted between 1200 and 1800 Hz for purposes of coding digital data. Since the modulating signal was applied to the microphone input of the radio for transmissions, they passed through the circuits incorporating preemphasis, clipping, and low pass filters, prior to entering the modulator circuit.

The antenna utilized at the base station was an omnidirectional high gain antenna operating in the 806-870 MHz range. A feature of this antenna was its ability to fill in the nulls between the main lobe and the first and second side lobe below the horizontal plane. It provided more uniform coverage over the test area than a base station antenna without this feature. The antenna was connected to the base station using approximately 100 feet of low-loss 7/8 inch Heliax cable.

The interface controller housed the circuitry necessary to receive, decode, reformat, and transmit messages to the vehicle unit. This controller also served to energize the transmitter turn-on and turn-off func-

tions.

1.3.3 Data Acquisition System

The Data Acquisition System (DAS) was completely contained in the test vehicle. This configuration allowed the maximum flexibility in recording and processing the collected data. The DAS consisted of a minicomputer, a cassette recorder, an A/D converter, a printer/keyboard, an odometer, and an interface controller. The DAS controlled the initialization of transmissions from the vehicle, the sampling of the received data, the odometer, and the monitor equipment. Tests were conducted in either of two sampling modes: distance or time. The sampling intervals in feet or in seconds, depending upon the test director's specifications, were input through the printer/keyboard. In the Distance Mode, polling was initiated by the odometer.

The cassettes were used for recording all the data input by the test operator through the keyboard and that generated by the two radios. Each cassette had the capacity to store 90,000 bytes, corresponding to approximately two hours of normal testing.

The A/D converter was a four-channel, ten-bit model requiring a system conversion time of 22 microseconds. The log output of the TSC receiver was fed into the A/D converter where the return (downlink) signal level was sampled at predetermined times.

The odometer equipment was used to verify the location of the recorded data relative to known locations which were periodically recorded on the cassette as event markers by the test operator.

Event marking was accomplished through the use of the keyboard. A manual input of an event code via the keyboard caused a new record to be entered. The event codes utilized were either preassigned route checkpoints or points determined during the actual run which were identified

by location and event code recorded on the test log.

The interface controller provided for the acquisition of data for recording via the minicomputer and cassette and also performed the coding and formatting functions for polling transactions.

1.4 Systems Performance

Most of the equipment utilized during the test was off-the-shelf. Certain units such as the interface controller were designed and fabricated by Gould I^3 personnel. The vehicle and base station equipment were integrated and an initial checkout performed at the Gould facilities in Fort Worth, Texas. After initial checkout, the equipment was shipped to Los Angeles for installation and checkout. A test director from Gould I^3 supervised the installation, checkout, and tests with the support of personnel from Gould ESD in El Monte, California.

The system was calibrated before each run and during each run as necessary. The system performance was investigated under a number of conditions of the fixed independent variables discussed in Section 1.1 The primary objective of the program from the Multi-User AVM system standpoint was to examine the possibility of achieving a 95 percent throughput overall and 75 percent throughput over any 0.1 mile segment of the designated AVM coverage area.

SECTION 2

SUMMARY

2.1 Test Configuration

The test configuration represents an effort to describe the complete system configuration. It entails a systematic treatment of the major components including:

1. Test vehicle
2. Communication equipment both on the vehicle and at the base station
3. Data acquisition equipment
4. Test sites
5. Test routes.

This overall description concerns itself not only with the description of each component in detail, but also sets the scenario for the tests that were conducted, where they were conducted, how they were run, what data were collected, and under what varying conditions the different effects were measured.

2.2 Test Results

The test results are dealt with exhaustively starting with the type of data reduction and analyses that were performed (as described in Section 3.4) and documenting the results of each of the following:

- Route profiles
- Large scale variation model comparisons
- Small scale variation results
- Message error mechanisms
- Antenna tests.

These results are discussed in detail in Section 4.

SECTION 3

TEST DESCRIPTION

3.1 Equipment

The equipment used in the test program can be classified into two categories:

- Base station equipment
- Vehicle equipment.

3.1.1 Base Station Equipment

The base station equipment utilized as a transponder for purposes of the test consisted of:

- The base station radio transceiver
- The base station antenna and accessories
- The GI^3 interface controller.

3.1.1.1 Base Station Radio Transceiver . The base station was General Electric MASTR® II with an output power variable from 30 to 90 watts. The station is capable of full duplex operation, but for purposes of the tests the operation was restricted to half duplex with the radio receiving digital data transmissions from the vehicle unit at 808.4375 MHz and transmitting modulated signals at 853.4375 MHz. The modulating frequency was shifted between 1200 and 1800 Hz to represent the two states of digital data transmitted. The modulating signal was applied to the radio through the microphone input, and therefore, as in the case of voice transmission, the data passed through preemphasis, clipping, and low-pass filtering circuits prior to entering the modulator circuit. The base station specification is shown in Figure 3-1.

3.1.1.2 Base Station Antenna. The base station antenna was a Decibel Products Model DB-480 omni-directional antenna. This antenna is char-

GENERAL DATA

CABINET STYLE	INDOOR CABINETS (floor mount)		INDOOR/OUTDOOR CABINET (wall or pole/crossarm mount)
Combination 1st Digit	"S"	"V"	"P"
SIZE			
Height:	44-1/4 ins. (113 cm.)	69-1/16 ins. (175 cm.)	45 ins. (114 cm.)
Width:	21-1/2 ins. (54.6 cm.)	23-3/16 ins. (59 cm.)	21-1/2 ins. (54.6 cm.)
Depth:	15.5 ins. (39.4 cm.)	21 ins. (53.3 cm.)	21 ins. (53.3 cm.)
WEIGHT Packed for Domestic Shipping	195 lbs. (88.4 kg.)	305 (139 kg.)	240 lbs. (109 kg.)
NUMBER OF RACK UNITS:	22	33	22

Note: One Rack Unit equals 1.75 inches. The basic radio unit, control and power supply occupy 11 rack units.

The indoor/outdoor "P" style cabinet is a weatherproof enclosure suitable for full outdoor exposure.

The front and rear doors are hinged on the same side of the cabinet so that one opens from the right and the other from the left. Both doors are gasketed and have provisions for locks.

The illustrations on the right show typical mounting arrangements. Note also that the cabinet may be mounted on the opposite side.

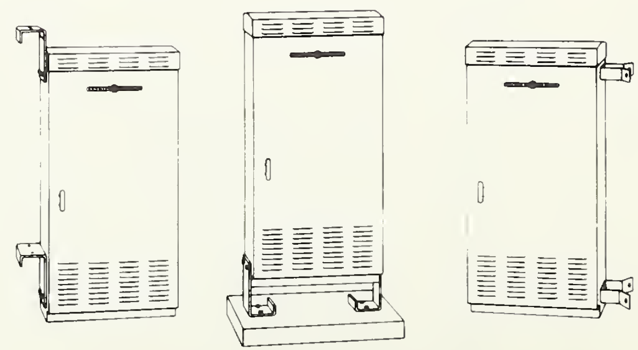


FIGURE 3-1 BASE STATION SPECIFICATION

PERFORMANCE DATA

DUTY CYCLE (EIA):	Continuous
AMBIENT TEMPERATURE (for full spec performance per EIA):	-30°C to +60°C (-22°F to +140°F)
HUMIDITY:	90% @ 50°C (EIA)
SOURCE POWER INPUT:	121 VAC (±20%), 60 Hz (Convertible for 242 VAC)
LENGTH OF AC POWER CABLE:	10 ft. (305 cm.)

ALTITUDE

Operable:	Up to 15,000 ft. (4.570m.)
Shippable:	Up to 50,000 ft. (15.250m.)

SOURCE POWER DRAIN	@121 VAC
Receiver	
Standby:	127 W
Rated Audio:	145 W
Transmitter:	540 W

METERING

Centralized metering sockets (receiver and transmitter driver) accommodate the TM-11 Test Set; or a single 0-3 VDC, 20,000 Ohms/Volt meter may be used. The PA has a built-in meter panel on the power supply.

FIGURE 3-1 BASE STATION SPECIFICATION (Continued)

TONE & DC REMOTE CONTROLLED STATIONS

AUDIO (line to transmitter)	
Line Terminating Impedance:	600 ohms, 150, 900 opt.
Line Level (adjustable):	-20 dBm to +11 dBm
Output Level to Transmitter (max.)	
Remote Station:	400 mV (adjustable)
Remote/Repeater Station:	200 mV (adjustable)
Frequency Response:	±3 dB @ 300-3000 Hz
Line Bridging Impedance:	3K ohms @300 Hz
TONE CONTROL	
Function Tones:	1050, 1150, 1250, 1350, 1450, 1550, 1650, 1750, 1850, 1950 & 2050 Hz
Secur-it Tone & Transmit Tone:	2175Hz
Transmitted 2175 Hz Tone Level	65 dB below voice
Permissible Control Line Loss	30 dB

AUDIO (receiver to line)	
Audio Amplifier	
Input Impedance:	40 K ohms
Input Level:	1 V r,s (330 mV per kHz deviation)
Output Impedance to Line:	600 ohms (150 & 900 opt.)
Output Level to Line	
Voice (1 kHz ref.):	0 VU (adjustable)
Tone (1 kHz ref.):	+11 dBm (adjustable)
Frequency Response:	+1 dB and -3 dB 300-3000 Hz
Hum and Noise	
Noise Squelch:	-55 dB (ref. 11 dBm)
Tone Squelch:	-30 dB (ref. 11 dBm)
DC CONTROL	
Control Currents:	-2.5 ±6 & ±11mA
Line Loop Impedance: (maximum)	11 K ohms (includes 3 K termination)

FIGURE 3-1 BASE STATION SPECIFICATION (Continued)

RECEIVER

Frequency Range:	806 to 825 MHz
RF Input Impedance:	50 ohms
Channel Spacing:	25 kHz
Sensitivity:	
EIA 12 dB SINAD	0.25 µv
20 dB Quieting	0.35 µv
Critical Squelch	4 dB SINAD
Channel Guard Squelch	6 dB SINAD
Selectivity: (EIA 2-Signal)	-80 dB
Frequency Stability: (1st Oscillator)	±0.0001% from -30°C to +60°C
Modulation Acceptance:	±7.0 kHz
Intermodulation:	-70 dB
Spurious and Image Rejection:	-100 dB
Audio Response:	Within +1 and -8 dB octave de-emphasis 300 to 3000 Hz per EIA
Audio Output:	5 watts into 8 ohms with less than 5% distortion (@1000 Hz)

TRANSMITTER

Frequency Range:	851 to 870 MHz
RF Power Output:	90 watts
Adjustable to:	30 watts
Output Impedance:	50 ohms
Spurious & Harmonic Emission	
Conducted:	66 dB
Radiated:	63 dB
Modulation Deviation:	0 to ±5 kHz (16F3, 15F2, 16F9)
Frequency Stability:	±0.0001% from -30°C to +60°C
FM Noise:	-55 dB
Audio Response:	Within +1 and -3 dB of 6 dB octave pre-emphasis 300 to 3000 Hz per EIA standards.
Audio Distortion:	Less than 2% (@ 1000 Hz)

FIGURE 3-1 BASE STATION SPECIFICATION (Continued)

acterized by a high gain (7.5 dB), an omni-directional radiation pattern, and a unique feature that fills the nulls between the main lobe and the first side lobe below the horizon. This improves the coverage of the antenna over the entire frequency range extending from 806 MHz to 870 MHz. The antenna was connected to the base station through the use of 7/8 inch Heliax cable whose total losses were 1 to 1.5 dB. The antenna specification is shown in Figure 3-2.

3.1.1.3 Base Station Interface Controller. This unit contained the circuitry necessary to receive, decode, reformat, and retransmit the received signals, and also the circuitry to control the base station itself. The 32-bit messages, consisting of two 16-bit words (interrogations) received by the base station in the B-$\overline{\text{B}}$ format, were reformatted into 56-bit messages by repeating the 16-bit word three and one-half times, and then transmitted back to the vehicle unit. Another function performed by the controller was that of energizing the line by closing the PTT switch when the received message was decoded, reformatted, and ready for transmission.

A block diagram of the base station is illustrated in Figure 3-3.

3.1.2 Vehicle Unit Equipment

Figure 3-4 shows the layout of the test vehicle equipment. The Data Acquisition System equipment and communication equipment housed in the test vehicle were accommodated in the special racks. The printer/keyboard was positioned on the table in front of the test operator so as to provide easy access to the keyboard. From his position, the operator had a clear view of the right-hand forward quarter and was thus able to identify and "mark" all events along a test run. The strip-chart recorder was also located on the table, enabling the operator to exercise control of this instrument. The power allocation of the vehicle equipment is shown in Table 3-1. The frequency of the power plant was 61

ELECTRICAL

Frequency range	806-870 MHz
Gain (over half wave dipole)	7.5 dBd
Bandwidth (within 1.5 to 1 VSWR)	64 MHz
VSWR (Ref. to 50 ohms)	1.5 to 1 or less
Rated power input	500 watts
Elevation pattern beamwidth (half power points)	10°
Antenna termination: Type N female at base	
Pigtail termination: Type N male	

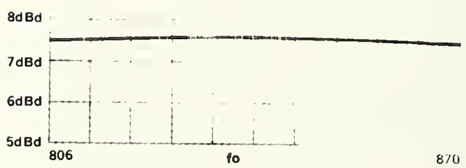
MECHANICAL

Materials:	
Radome	Fiberglass
Radiating assembly	copper
Mounting support	Two steel collars separated 6 1/2" for attaching mounting clamps
Mounting clamps	Zinc/Chromated
Maximum exposed area (Flat Plate Equivalent)	1.5 sq.ft.
Wind rating	
Survival (w/o ice)	150 mph
Survival (1/2" radial ice)	135 mph
Bending moment at top clamp at 100 mph (40 psf flat equivalent)	211 ft. lbs.
Lateral thrust at 100 mph (40 psf flat equivalent)	60 lbs.
Length (806-870 MHz)	96 1/2"
Radome diameter	3 1/2"
Net Weight (w/clamps)	16 lbs.
Shipping weight (w/clamps)	30 lbs.

Mounting clamps are supplied with the antenna to fit around tower members up to 3 1/2" OD, angle members up to 2 3/4". Other size clamps can be furnished on special order.

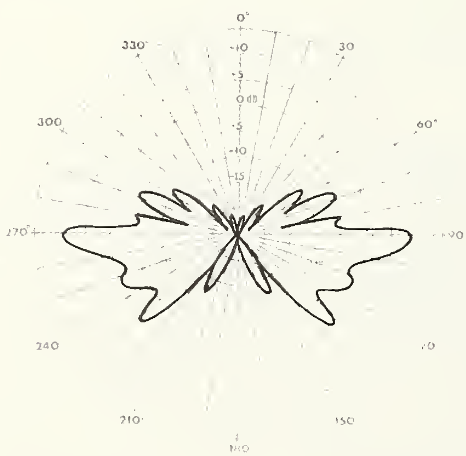
FIGURE 3-2 BASE STATION ANTENNA SPECIFICATION

ANTENNA GAIN VS FREQUENCY



Curve illustrates the gain of a DB-480 Antenna across its 64 MHz bandwidth. Maximum gain of 7.5 dBd occurs at the mid-band frequency (fo) of the frequency range.

DB-480 ELEVATION RADIATION PATTERN



The pattern above illustrates a typical Elevation Plane radiation of a DB-480 antenna when top mounted on supporting structure.

FIGURE 3-2 BASE STATION ANTENNA SPECIFICATION (Continued)

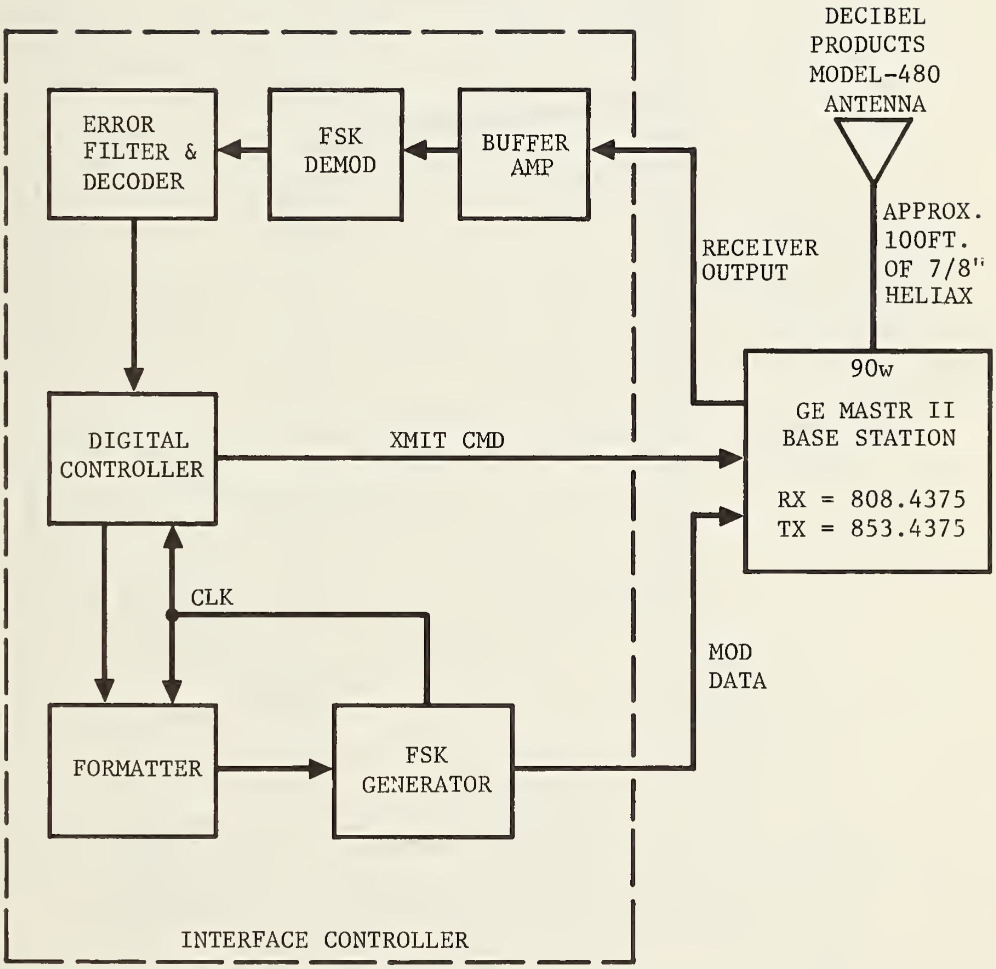


FIGURE 3-3 BASE STATION EQUIPMENT BLOCK DIAGRAM

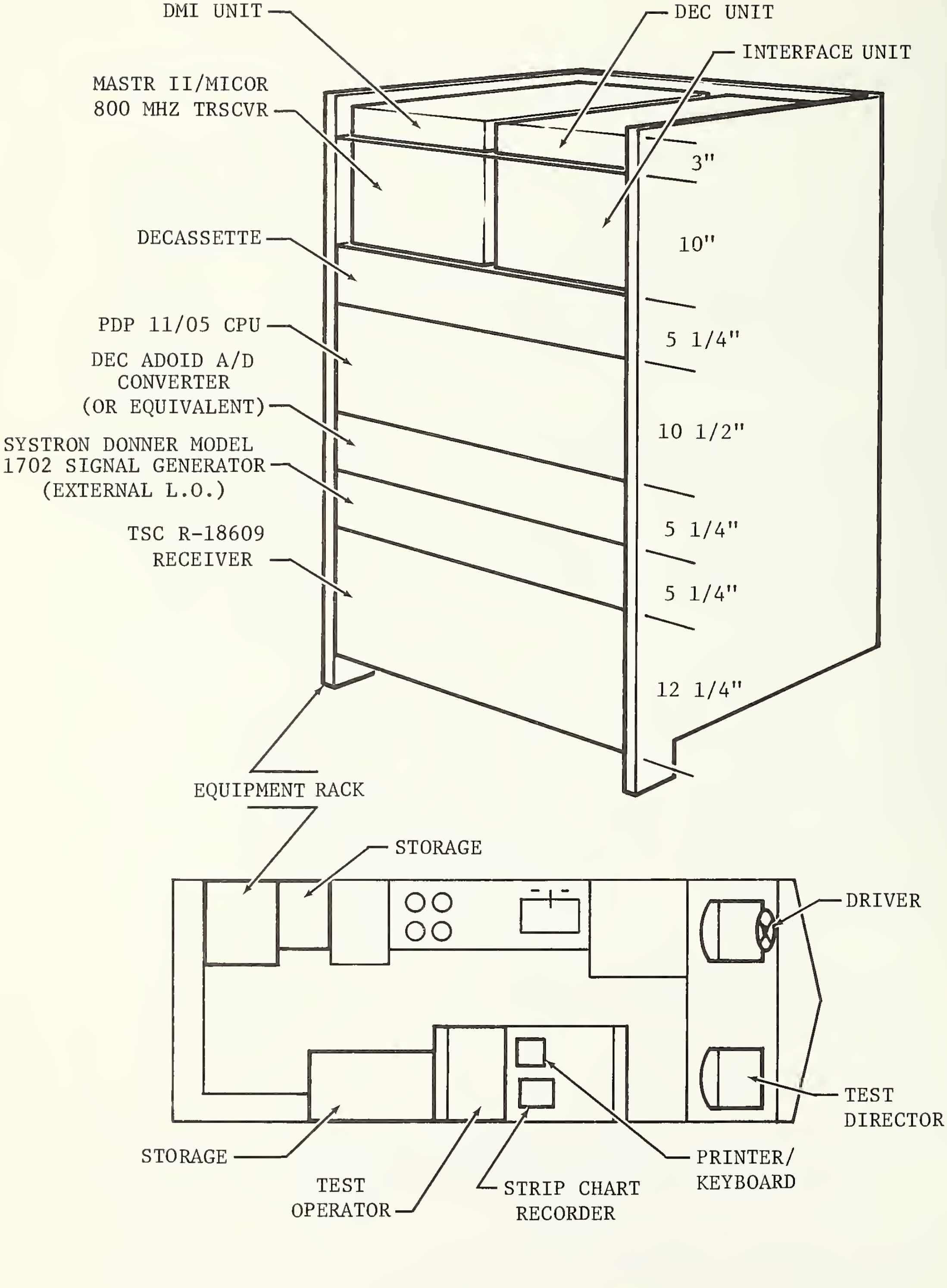


FIGURE 3-4 TEST VEHICLE EQUIPMENT LAYOUT

TABLE 3-1 VEHICLE POWER REQUIREMENTS

COMPONENT	VOLT-AMPS AT 115 VAC	PEAK AMPS AT 12 VDC
Mobile Radio		13 Peak
PDP 11/05	600	
Cassette	120	
ADOI-D A/D Converter	60	
TI 733 Printer	200	
TSC Receiver	300	
Systron Donner Signal Generator	75	
Strip Chart Recorder	200	
ICU Power Supply	200	
DMI Unit of Odometer		1.6
DEC Unit of Odometer		0.3
Air Conditioning Equipment	1500	
	3250 VA	14.9 A Peak

Hz unloaded with a ±10% variation for all conditions of loading. These excursions were found to be within the specifications of all instrumentation equipment.

The vehicle equipment consisted of both the communication equipment located in the vehicle and the Data Acquisition System equipment.

3.1.2.1 Vehicle Communication Equipment. The communication equipment on the vehicle unit consisted of the following:

- GE MASTR® Executive II and Motorola MICOR™ Mobile Radios
- Mobile Transceiver Antenna
- TSC R-18009 Receiver (Modified)
- Hybrid Junction and Coaxial Switch
- Vehicle Interface Controller.

The GE Executive II and Motorola MICOR mobile radios are commercial 35-watt transceivers capable of operating in the new 800 MHz land-mobile band. These units transmit in the 806-825 MHz frequency range and receive in the 851-870 MHz frequency range. For the purposes of the test program, the units were operated in the half-duplex mode. Detailed specifications of the radios are contained in Figures 3-5a and 3-5b.

The mobile radio was used to interrogate the base station by the use of digital transmissions consisting of 32 bits of information. This information was generated by repeating a 16-bit word twice and adding a preamble and postamble. The initial polling transmissions were initiated by the use of a pseudo-randomly generated bit pattern from the minicomputer. These messages were then coded in the B-$\overline{B}$ format. After being received at the base station and retransmitted as a 56-bit message in the B-$\overline{B}$ format, the transmitted message was then fed into both the TSC receiver and the mobile radio receiver; after appropriate decoding, this message was categorized as one of the four possible outcomes in con-

806 to 870 MHz Operation

GENERAL

MODEL SERIES	RF POWER OUTPUT (WATTS)	PA POWER INPUT (WATTS)	BATTERY DRAIN (Amps)			FCC FILING NUMBER	APPLICABLE TO PART NUMBER (FCC RULES)	RECEIVER FCC MODEL NUMBER
			Rx Standby	Unsquelched	Transmit			
RT55	35	120	0.5@ 13.8 VDC	1.75@ 13.8 VDC	13 @ 13.6 VDC	KT-147-C	89,91 &93	ER-96-C

NOMINAL SYSTEM VOLTAGE:	13.8 VDC+20%, negative ground
DUTY CYCLE:	Receiver, 100% - Transmitter, 20% per EIA
TEMPERATURE RANGE:	Operable over ambient temperature range -30°C to +60°C (-22°F to +140°F)
HUMIDITY:	95% RH @ 50°C
SHOCK & VIBRATION:	Meets EIA & U.S. Forest Service Specifications
DIMENSIONS (HxWxD)	
Mobile Unit:	3.9x13.5x13.4 inches; 9.9x34.3x34cm.
Control Head:	3.1x5.5x3.4 inches; 7.8x14x8.5cm.
Speaker:	5.1x5.5x3.5 inches; 13x14x8.9cm.
WEIGHT (Average)	
Unit and Accessories:	29 lbs.; 13.2 kg.
Shipping (Domestic Pack):	32 lbs.; 14.5 kg.
ANTENNA:	All stainless steel, 1/4 wave whip, Chrome & Lexan® base with 15 ft. (4.57m.) antenna cable.
MOUNTING:	Hardware and cables supplied for trunk installation
POWER/CONTROL CABLE:	19C303910G2 for 1 Freq. C-300 Control Unit. 19C303910G4 for 4 Freq. C-300 Control Unit.
SPEAKER:	3.2 ohms
MICROPHONE:	Controlled Magnetic

FIGURE 3-5a MASTR® EXECUTIVE II MOBILE RADIO SPECIFICATION

RECEIVER

Frequency Range:	851 to 870 MHz
RF Input Impedance:	50 ohms
Channel Spacing:	25 kHz
Sensitivity:	
EIA 12 dB SINAD	0.25 μv
20 dB Quieting	0.35 μv
Noise Squelch	4 dB SINAD
Channel Guard Squelch	6 dB SINAD
Selectivity EIA 2-Signal	-75 dB
Frequency Stability:	±0.0002% from -30°C to +60°C
Modulation Acceptance:	±7 kHz
Intermodulation:	-70 dB
Spurious and Image Rejection:	-100 dB
Audio Response:	Within +1 and -8 dB of 6 dB/octave de-emphasis, 300 to 3000 Hz per EIA.
Audio Output:	5 watts, 5% distortion (1000 Hz ref.)
Frequency Separation (Optional, 2 to 4 channels)	
Full Specifications (MHz):	1.6
3 dB Sensitivity Degradation (MHz):	3.0

TRANSMITTER

Frequency Range:	806 to 825 MHz
RF Power Output:	35 watts
Adjustable:	12 watts
Spurious and Harmonic Emission:	62 dB below carrier
Modulation Deviation:	0 to ±5 kHz (16F3,15F2)
Frequency Stability:	±0.0002% from -30°C to +60°C
FM Noise:	-55 dB
Audio Response:	Within +1 and -3 dB of 6 dB/octave pre-emphasis, 300 to 3000 Hz per EIA
Audio Distortion:	Less than 2% @ 1000 Hz
Frequency Separation (max.) (Optional, 2 to 4 channels)	
Full Specifications (MHz):	3.0

FIGURE 3-5a MASTR® EXECUTIVE II MOBILE RADIO SPECIFICATION (Continued)

GENERAL

No. of Frequencies:	One and five frequency models available
Squelch Options:	Carrier Squelch - 1000 series models "Private Line"(TM) tone-coded squelch - 3000 series models "Digital Private-Line" (TM) coded squelch - 6000 series models
Dimensions:	3 3/8"Hx13"Wx17 1/2"L (85 mm x 330 mm x 450 mm)
Weight:	Approx. 25 lbs. (11,4 kg) Ship Wt. approx. 50 lbs. (22,7 kg)
Metering:	A single-scale 0 to 50 microampere meter or Motorola Portable Test Set can be used to measure all circuits essential to tuning and checking.

Freq. (MHz)	Model Series	EIA Intermittent Minimum Rf Power Output	Cont. Duty Power Output	Operation	Max. Batt. Drain		
					Stdby. @13.8V	Rcvr. @13.8V	Transmit @13.6V
806-821TX/ 851-866RX	T45RTA	35W	30W	12V dc	.6A	2.7A	13A

FIGURE 3-5b. MICOR(TM) MOBILE RADIO SPECIFICATION

TRANSMITTER

RF POWER OUTPUT:	35 Watts
Output Impedance:	50 ohms
Frequency Stability:	Chan. ele. maintains osc. stab. within ±00025% from -30°C to +60°C ambient, +25°C ref. ±15% primary voltage variation
Spurious & Harmonics:	-80 dB
Modulation:	15F2 & 16F3, ±5 kHz for 100% @ 1kHz
Audio Sensitivity:	0.080V ±3 dB for 60% max. deviation @1000 Hz
FM Noise:	55 dB below 60% max. deviation @1000 Hz
Audio Response:	+1, -3 dB of a 6 dB per octave pre-emphasis characteristic from 300 to 3000 Hz
Audio Distortion:	Less than 3% @ 1000 Hz, 60% max. deviation
Maximum Frequency Separation:	5 MHz
FCC Designation:	CC5010-licensable under FCC Rules Parts 89,91 and 93 for 15F2 16F3 emissions

RECEIVER

Channel Spacing:	SPLIT CHANNEL 25 kHz
Sensitivity- 20 dB Quieting: EIA SINAD:	 .5 μV .35 μV
Selectivity: (EIA SINAD)	-80 cB
Intermodulation: (EIA SINAD)	-75 dB
Spurious and Image Rejection:	-100 dB min.
Squelch Sensitivity- Carrier Squelch: (adjustable) Coded Squelch: (fixed)	 6 dB quieting (.25 μV) or less at threshold 6 dB quieting (.25 μV) or less
EIA Modulation Acceptance: Impedance: Audio Output:	± 9 kHz minimum 50 ohms 10 watts at less than 5% distortion (into an 8 ohm load at 1000 Hz)
Maximum Frequency Separation:	5 MHz
Frequency Stability:	Chan. Ele. maintains receiver stab. within ±.0003% from -30°C to +60°C ambient, +25C ref ±15% primary voltage variation.

FIGURE 3-5b MICRO(TM) MOBILE RADIO SPECIFICATION (Continued)

junction with the interface controller and the minicomputer.

The four possible outcomes were as follows:

1. Response received/no message error detected
2. Response received/message error detected
3. No response (indicates an uplink error)
4. Response received/response error detected.

Whenever an error occurred, the message was recorded in order to facilitate off-line analysis.

The mobile antenna configuration was selected on the basis of two considerations. In the first place, the antenna had to be shared by both the TSC receiver and the mobile transceiver. Secondly, the test had to simulate the situation where the actual gains and losses of the SCRTD environment could be created. The first consideration was required in order to insure that the fades seen in the recorded data were the same in the case of both the TSC receiver and the mobile transceiver, since the former was used for S/N measurements and the latter for throughput measurements. Unfortunately the power splitter used for this purpose involved a loss of 3.5 dB to both the received and transmitted signals. To protect the input circuits of the TSC receiver, a coaxial switch was used and activated during the transmit period. The addition of the power splitter and coaxial switch also effectively degraded the sensitivity of the TSC receiver by 4 dB. A low- profile antenna with an effective gain equivalent to a 1/4 monopole was used for the mobile antenna. The data sheet for the mobile antenna is shown in Figure 3-6.

The TSC receiver was used to quantify the characteristics of the 800 MHz channel. This was required due to the lack of any other means of measuring/monitoring signal and noise levels on the commercial FM transceiver.

MANUFACTURER: ANTENNA SPECIALIST

MODEL NUMBER: D-106R (Prototype)

ELECTRICAL SPECIFICATIONS:

Gain	Unit, equivalent to 1/4 λ monopole
Max Power	50 watts
Frequency Range	806 to 866 MHz
VSWR	< 1.5:1
Bandwidth	60 MHz
Nominal Impedance	50 ohms

MECHANICAL SPECIFICATIONS:

Radiator Material	Silver plated brass
Radome Material	High impact molded ASA TM
Radome Color	White
Connector	SO-239
Height	3 3/8"
Length	8"
Width	3 1/2"
Mounting Hardware	Supplied with 4 No. 10 stainless steel Truss slotted bolts and 4 self-tapping Hex Head sheet metal screws. a 1/8" rubber mounting pad is included
Cable	Supplied with special low loss teflon cable with right angle UHE male connector on one end

FIGURE 3-6 800 MHz HARD-HAT ANTENNA SPECIFICATION

The TSC receiver provided a log output and had an 80 dB dynamic range, making it ideal for measuring absolute signal strength. For the purpose of these tests, the bandwidth of the TSC receiver was modified to correspond to the bandwidth of the commercial radio. The modifications were primarily in the preselector filter, external local oscillator, and the second IF filter. In order to more closely approximate the commercial FM transceiver characteristics, a cavity resonator was added to the front end of the receiver to reduce the RF bandpass to approximately 2 MHz. This resulted in a loss of about 1 dB, but this was considered acceptable. A precision crystal local oscillator was used to furnish the external local oscillator drive of +7 to +10 dBm.

The IF filter used to reduce the minimum IF bandwidth from 200 KHz to 16 KHz incorporated the use of an 8-pole monolithic crystal filter with a 3 dB bandwidth of 16 KHz and a 60 dB bandwidth of 32 KHz. This still did not provide the adjacent-channel rejection which is provided by commercial radios (10 pole); however, since no strong adjacent channel was present, it was deemed sufficient to adequately represent the characteristics of a commercial mobile radio for purposes of this test. After modification the tangential sensitivity of the TSC receiver was measured to be -11 dBm at the input to the cavity preselector. The log output of the receiver was terminated in the A/D converter where it was sampled under processor control to obtain and record samples of signal and noise power levels.

3.1.2.2 Data Acquisition System (DAS). DAS equipment was completely contained in the vehicle unit. It consisted of the following items:

- The PDP 11/05 minicomputer
- Cassette Recorder
- AD01 A/D converter

- TI 733 Silent Printer
- Nutronics Distance Measuring Instrument and the Distance Event Marker
- Interface Controller.

A complete block diagram of the vehicle equipment is shown in Figure 3-7. The DAS controlled (1) the initiation of interrogation transmissions, (2) the sampling of the received data, and (3) the recording of odometer and monitor equipment. The tests were conducted in one of two modes: distance or time. The sampling mode (time or distance) and the sampling interval (seconds or feet) was specified by the operator through the keyboard. The recorded data consisted of header records and the actual data records. The header details were input via the keyboard and contained the following information:

- Run Number
- Date
- Start Time
- Operating Mode
- Calibration Data

A sample printout of the header details are shown in Figure 3-8. The calibration data consisted of the following information:

- Feet or seconds per poll, depending on Operating Mode
- Odometer feet per pulse
- Number of polls per output line
- Baud rate

In Mode 1, the odometer initiated polls and the base station was polled at an interval controlled by the Distance Event Controller (DEC) and the computer. The desired distance between polls was input by the operator.

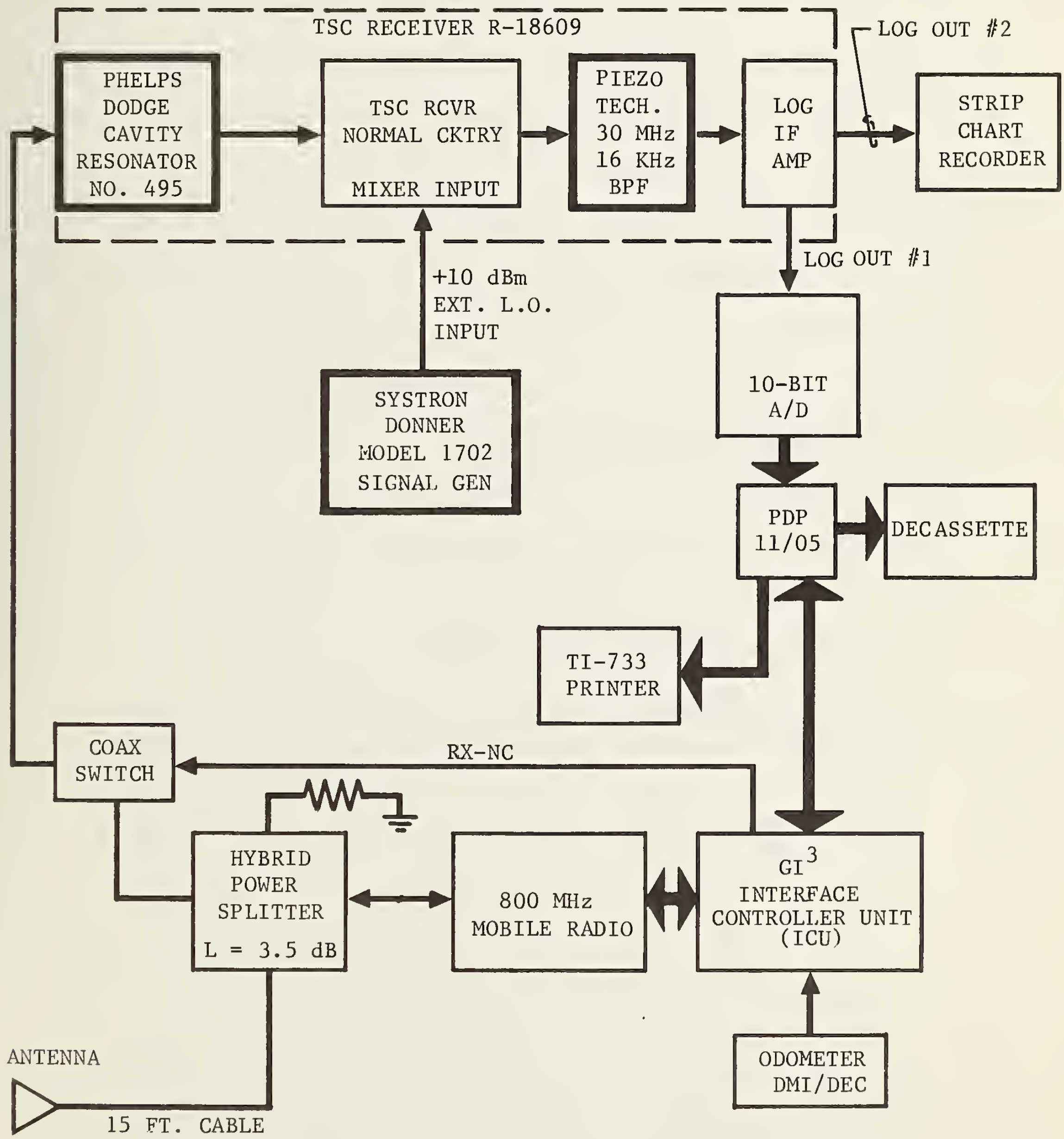


FIGURE 3-7 VEHICLE EQUIPMENT BLOCK DIAGRAM

(1) RUN NO = 2

(2) DATE = 1/13/78

(3) TIME = 10/30

(4) RECORD MODE = 0

HEADER LABELS

---

(1) FEET PER POLL = 0(50 IN MODE 1)

(2) SECONDS PER POLL = 1

(3) ODOMETER FEET PULSE = 2

(4) NO. OF POLLS PER PRINT LINE = 10

(5) BAUD RATE = 1500

CALIBRATE

TIME MODE
POLL EVERY 0000.1 SECOND

ATTEMPTS	UPLINK ERROR	DOWNLINK ERROR	MESSAGE ERROR	RNDTRPS	SIGNAL LEVEL HIGH	LOW	NOISE LEVEL HIGH	LOW
0010	000	100	000	10	777	000	776	000
0010	000	000	000	10	777	258	777	258
0010	000	000	000	10	519	000	519	000

FIGURE 3-8 HEADER AND PRINTER EXAMPLE

In Mode 2, the poll was based on a time interval such that the base station was polled at intervals corresponding to the rate (in tenths of seconds) entered by the operator.

The input corresponded to the setting of the control thumbwheel switch on the Distance Event Controller. This input also conveyed to the computer the sample size of the data to be summarized and printed out. This provided for the real-time monitoring of the data to determine variations, if any, of the normal procedure. Finally, this input was used by the computer to control the number of samples to be measured and averaged during each message interval.

The response to interrogations was classified under one of four categories as explained in Section 3.1.2.1. The first response, "valid response/no message error," corresponded to the condition where the received message passed the error filter and was also identical to the transmitted message. The data record for this response consisted of five 16-bit words. The data sample was recorded in the form of an 80-bit record as follows:

Item	Bits
Event Code (E)	9
Time (M), (S), (.15)	16
Average Signal Level (A1)	10
Average Noise Level (A2)	10
Peak Fade Level (A3)	10
Response Code (K)	3
Odometer (O)	16
Spares	6
Total	80

The second type of response corresponded to the condition where an

uplink error occurred. Interrogations were sent, but responses were not received. The data record for this response consisted of a 6-word, 96-bit record. That is, the 16-bit transmit code message was also recorded on tape. The third type of response corresponded to a downlink error in which a response was detected at the receiver but the message failed to pass the error filter. The fourth type of response corresponded to a message that passed the error filter but failed to match the transmitted message in one or more of the 3.5 cells. This corresponds to an undetected error. Data records for the latter two responses were identical and utilized 160 bits. A sample of the data record for these responses is shown below:

Item	Bits
Event Code (E)	9
Time (M), (S), (.15)	16
Average Signal Level (A1)	10
Average Noise Level (A2)	10
Peak Fade Level (A3)	10
Response Code (K)	3
Odometer (0)	0
Transmit Code (T)	16
First 16-Bit Response Code (RI)	16
Second 16-Bit Response Code (R2)	16
Third 16-Bit Response Code (R3)	16
Fourth 8-Bit Response Code (R4)	8
Spares	14
Total	160

The basic data record format is shown in Figure 3-9.

GOOD RESPONSE NO ERROR

S_1	S_1	S_1	S_1	K	K	K	E	E	E	E	E	E	E	E	E
S_o	S_o	S_o	S_o	S_o	S_o	A_1	A_1	A_1	A_1	A_1	A_1	A_1	A_1	A_1	A_1
M	M	M	M	M	M	A_2	A_2	A_2	A_2	A_2	A_2	A_2	A_2	A_2	A_2
						A_3	A_3	A_3	A_3	A_3	A_3	A_3	A_3	A_3	A_3
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

UPLINK ERROR

S_1	S_1	S_1	S_1	K	K	K	E	E	E	E	E	E	E	E	E
S_o	S_o	S_o	S_o	S_o	S_o	A_1	A_1	A_1	A_1	A_1	A_1	A_1	A_1	A_1	A_1
M	M	M	M	M	M	A_2	A_2	A_2	A_2	A_2	A_2	A_2	A_2	A_2	A_2
						A_3	A_3	A_3	A_3	A_3	A_3	A_3	A_3	A_3	A_3
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T

DOWNLINK ERROR/GOOD RESPONSE AND ERRORS

S_1	S_1	S_1	S_1	K	K	K	E	E	E	E	E	E	E	E	E
S_o	S_o	S_o	S_o	S_o	S_o	A_1	A_1	A_1	A_1	A_1	A_1	A_1	A_1	A_1	A_1
M	M	M	M	M	M	A_2	A_2	A_2	A_2	A_2	A_2	A_2	A_2	A_2	A_2
						A_3	A_3	A_3	A_3	A_3	A_3	A_3	A_3	A_3	A_3
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T	T	T	T	T	T	T	T	T	T	T	T	T	T	T	T
R_1	R_1	R_1	R_1	R_1	R_1	R_1	R_1	R_1	R_1	R_1	R_1	R_1	R_1	R_1	R_1
R_2	R_2	R_2	R_2	R_2	R_2	R_2	R_2	R_2	R_2	R_2	R_2	R_2	R_2	R_2	R_2
R_3	R_3	R_3	R_3	R_3	R_3	R_3	R_3	R_3	R_3	R_3	R_3	R_3	R_3	R_3	R_3
								R_4	R_4	R_4	R_4	R_4	R_4	R_4	R_4

S_1 - .1 SECONDS

E - EVENT CODE

A_1 - A/D(SIGNAL LEVEL)

A_2 - A/D(NOISE LEVEL)

0 - ODOMETER VALUE

K - RESPONSE CODE

S_o - SECONDS

M - MINUTES

A_3 - PEAK FADE LEVEL

T - CODE TRANSMITTED

R_1 - 1ST WORD OF RESPONSE

R_2 - 2ND WORD OF RESPONSE

R_3 - 3RD WORD OF RESPONSE

R_4 - 4TH HALF-WORD OF RESPONSE

IF K =

0	0	1	-GOOD RESPONSE (NO MESSAGE ERROR) (5 WORD)
0	1	0	-UPLINK ERROR (INT./NO RESPONSE) (6 WORD)
1	0	0	-DOWNLINK ERROR (RESPONSE/ERROR) (10 WORD)
0	0	0	-GOOD RESPONSE (UNDETECTED MESSAGE ERROR) (10 WORD)

FIGURE 3-9 BASIC DATA RECORD FORMAT

Since the cassettes were ultimately to be transferred to another media (floppy disks), they could be reused, and a seven-day (12-hour) supply of cassettes proved adequate. A total of more than 80 cassettes were used.

The A/D converter is a four-channel, ten-bit model with a system conversion time of 22 microseconds. The analog (log-video) output of the TSC Monitor Receiver was fed into the A/D converter, where the return message signal level was sampled at predetermined times after the response. The specifications of the A/D converter are shown in Figure 3-10.

The signal samples, A1 (i), and noise samples, A2 (i), were averaged by the minicomputer and recorded on tape as the average signal and noise levels A1 and A2. Samples were taken at a sampling rate of KHz, corresponding to time intervals of 500 usec to insure that fast-fade variations were detected. The minicomputer also determined and recorded the peak signal fade level during the message sampling interval, and designated this parameter as A3. (The peak signal fade level is the minimum signal level observed during a sampling interval).

The odometer equipment was used for verifying the location of recorded data relative to known locations as recorded on the tape as event markers. The equipment was also used in the Odometer Record Mode in conjunction with the computer to control the polling rate of the mobile radio. The odometer had the following controls:

DMI Control	Function
Thumbwheel	Programs DMI to calibrate unit
On-Off	Turns 12 VDC power on and off
Hold	Holds accumulated distance on DMI display and stops pulse stream to ICU

SPECIFICATION

Resolution:	Unipolar 10 bits, or 1 part in 1024 Bipolar (option) sign + 10 bits
System Accuracy:	0.1% of full scale (FS) input
Quantizing Error:	± 1/2 least significant bit
System Conversion Time: (Includes Channel and Gain)	Unipolar: 22 sec Bipolar: 29 sec
Sample and Hold:	Acquisition: 5 sec to ± 0.01% of FS step Aperture: 100 nanoseconds
Analog Input Channels:	4 minimum, expandable to 32 in groups of 4
Input voltage range: (program selectable)	Unipolar: 0 to + 1.25, + 2.5, + 5.0, + 10.0v FS Bipolar (option): 0 to ± 1.25, ± 2.5v, ± 5.0, ± 10.0v FS
Input Impedance :	1000 megohms in parallel with 20 pf
Input Isolation:	Enhancement mode MOSFET switches, "off" when unselected or power off.
Analog Input Connectors:	Plug-in cable-module
Channel Selection: (program selectable)	6 bit address
Cross channel attenuation:	78 db, DC-80 Hz for 20 volts p-p signals, 100 ohm source impedance
Input Gain:	Program selectable
Modes of Operation:	Interrupting/non-interrupting (program selectable) Synchronous (Program control) Asynchronous (External clock enable + 2.0v minimum into Schmidt trigger, repetition rate, 60k Hz maximum.)
REGISTER ADDRESSES	
Control and Status (ADCS)	776 770
Data Buffer (ADDB)	776 772
UNIBUS INTERFACE	
Interrupt vector address:	130
Priority level:	BR4 to 7
Bus loading:	1 bus load

FIGURE 3-10 AD01 A/D CONVERTER SPECIFICATION

Reset	Resets accumulated distance on DMI display and upon release, starts pulse train to ICU
Calb.	When pressed, allows unit calibration to be modified

DEC Control	Function
On-off	Turns 12 VDC power on and off
Hold	Stops pulse train output to ICU
Thumbwheel	Selected distance, N, between output pulses (0-9999)
Reset	Resets distance interval to 0
Mark	Normal event marker pulse output to ICU.

The DEC provided a 12-volt DC pulse every N feet as selected via the thumbwheel. This pulse was supplied to the interface unit where it was buffered and supplied to the computer as an interrupt which in turn was used for the data record or to initiate polling cycles.

The vehicle speed was determined off-line from the odometer and time records. When vehicle speed was of interest, the primary mode of operation was to poll at the fastest rate possible (0.3 to 0.5 seconds) while recording time and elapsed distance. At this polling rate, the resolution of the speed measurement was approximately ± 2 MPH.

Event marking was accomplished through the use of the keyboard. Whether under time or distance control, a manual input of an event code via the keyboard caused a new record to be recorded. If a poll was in progress, software control caused the event-generated poll to be initialized as soon as the previous response cycle was complete. The event code was initiated by pressing, in sequence, the appropriate (1) Event Function Key, (2) the Event ID Number, and (3) the SEND MESSAGE

Key. The event code corresponded either to preassigned route checkpoints or reference locations which were determined during the test run and subsequently identified by location and event code in the test log.

The interface controller controlled the acquisition of data for recording via the minicomputer cassette, and also performed the encoding and formatting functions for polling transmissions. The block diagram of the ICU is shown in Figure 3-11. The interface between the computer and the ICU corresponded to the following sequence of events, in order:

1. An interrupt is generated by the computer telling the controller to initiate a poll.
2. A 16-bit message (TX data) is transferred from the DR11-C to the interface controller buffer register.
3. After a preset delay corresponding approximately to the anticipated start of the response message, the controller begins sampling and begins A/D conversion of the output of the TSC receiver and samples the output of the carrier detect circuitry.
4. The ICU generates an interrupt (RX data) notifying the computer that a valid word is available.
5. The computer transfers 16 x 4 words from the interface unit to the DR11-C and acknowledges, or
6. If no interrupt (RX data) is generated within a fixed time interval (cycle window), the response is interpreted by the processor as an uplink error.
7. After a preset delay corresponding to a point in time after the response message, the controller begins sampling and A/D conversion of the output of the TSC receiver for channel noise.
8. The cycle repeats under software or operator control.

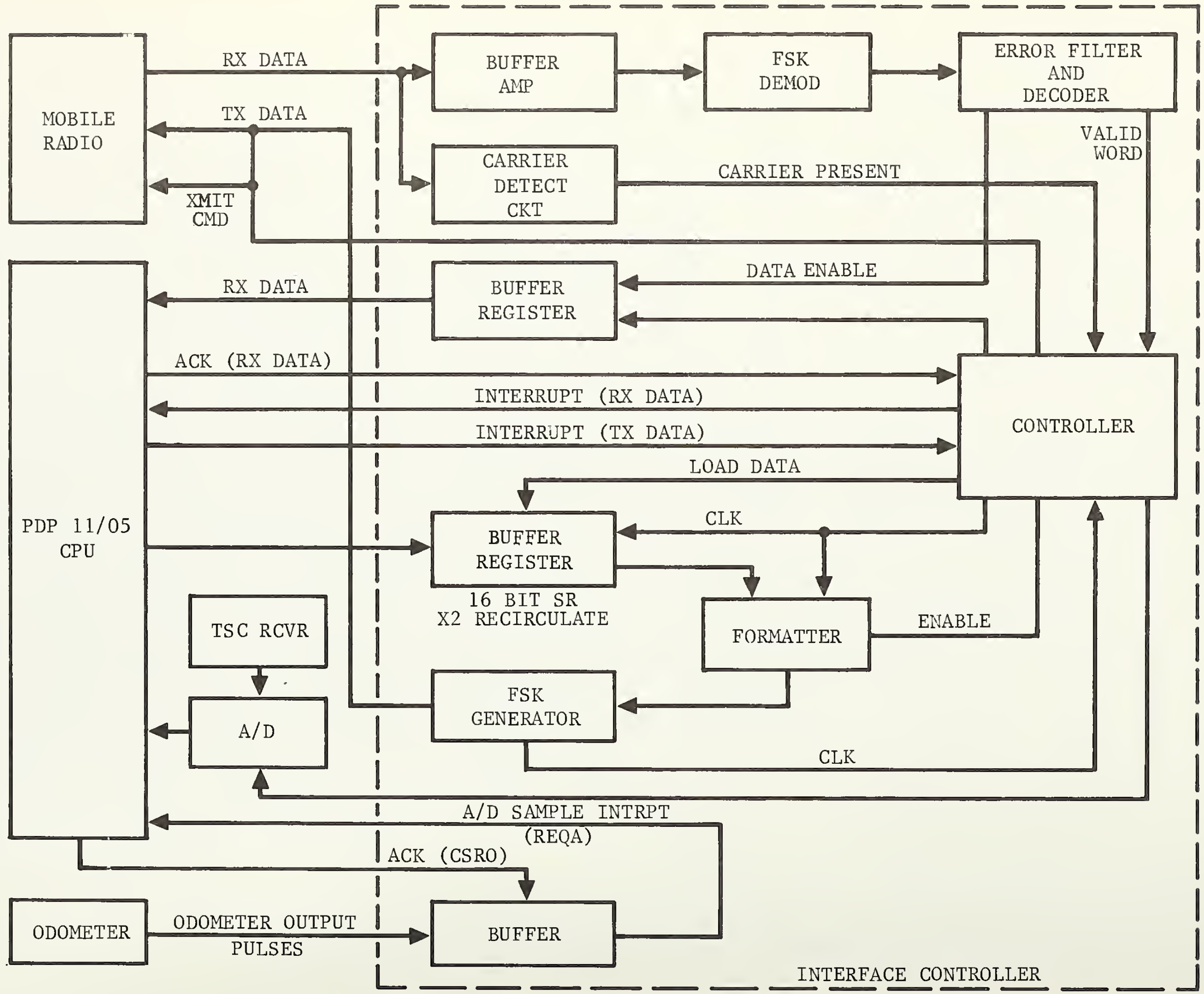


FIGURE 3-11 ICU BLOCK DIAGRAM

The DAS had the capability of printing (on the printer) selected data used in the test, calibration, and verification of operation of the system. The printer also generated error messages when input parameters were not compatible with the system constraints. In either record mode, the operator could select a sample population (entered through the keyboard) of polls to be summarized and printed out for real-time test monitoring. The printed information consisted of (1) the number of polls attempted (sample size), and (2) the number of errors and successful round trips. From this printout, problem areas could be identified and desired variations in the scenarios made in a timely manner. In addition, the variations in S/N for the sample group could also be printed out.

3.2 Routes

In general, the baseline SCRTD test routes were run in the survey mode at relatively low sample rates. However, when regions of marginal or poor performance were detected, test runs were made at higher sample rates, to aid in channel characterization and in identifying error sources. The baseline routes consisted of six SCRTD routes, the 30-square-mile-wide area coverage region including the downtown Los Angeles CBD, and along selected freeways between Santa Monica on the west, West Covina on the east, Long Beach Harbor on the south, and the southern exposure of the San Gabriel Mountains on the north.

3.2.1 Transit Routes

The six SCRTD routes selected at the time the tests were initiated were Lines 2, 7, 26, 29, 65, and 83. Later, Line 65 was replaced by Line 142, Line 2 with Line 41, and Line 89 added. Tests on these routes or segments of these routes were conducted by traversing them and polling at a sample rate of 50 feet per poll, unless the measured data indicated throughput below a criterion of eight successes out of

ten attempts, indicating areas where throughput was below 80 percent over 0.1 mile segments. The general geographic area covered by these routes is shown in Figure 3-12.

3.2.2 Wide Area Coverage Region

The wide area coverage region covered approximately 30 square miles. The area is outlined in Figure 3-13, and essentially covered the Central, Newton, and Rampart districts of the Los Angeles Police Department and included the Central Business District, an industrial area, a large commercial area, and sizeable residential area. It also included an expansive flat area and an area in the foothills of the San Gabriel Mountains. The 30-square-mile area is bounded on the east by the Los Angeles River, on the north by the Santa Monica Boulevard and Hyperion, on the west by Western, Interstate 10, and the Harbor Freeway, and on the south by Florence, Central, Slauson, Alameda and 25th Streets. The perimeter of this area is approximately 32 miles. The entire area was segmented into sections as shown in Table 3-2.

3.2.3 Selected Freeways and Arteries

In addition to the transit and random routes delineated above, selected freeways and arteries were chosen to determine channel characterization at increased range and coverage. These are shown in Table 3-3.

3.3 Test Procedures

3.3.1 Normal Procedure

At the start of each day's test, a "standard" calibrated test segment run was recorded to verify the proper functioning of the total system. The "standard" test segment consisted of a short segment where the S/N was high (>30 dB) and negligible interference or fading existed. The test segment was also so selected as to make line-of-sight operation

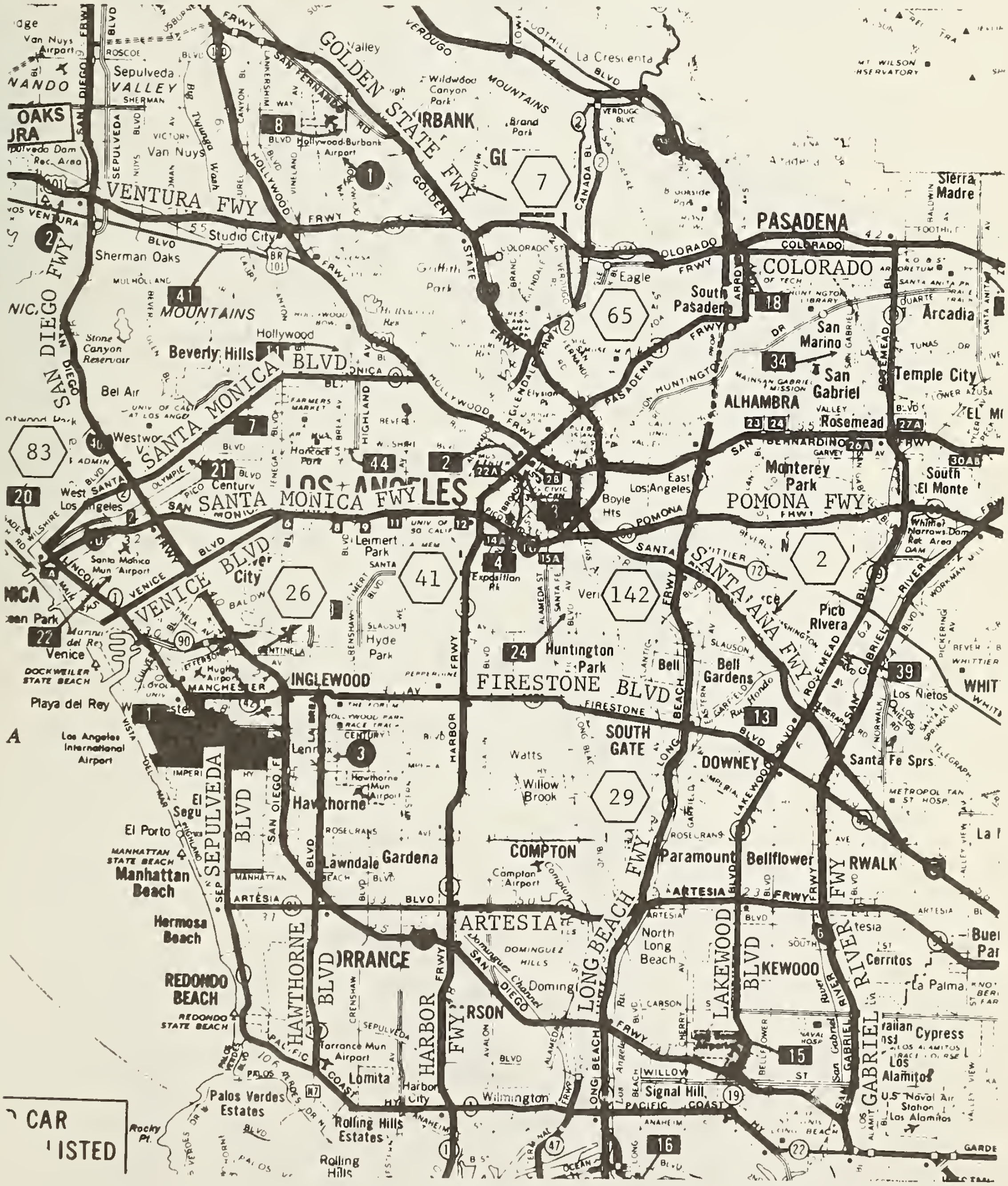


FIGURE 3-12 TEST ROUTES

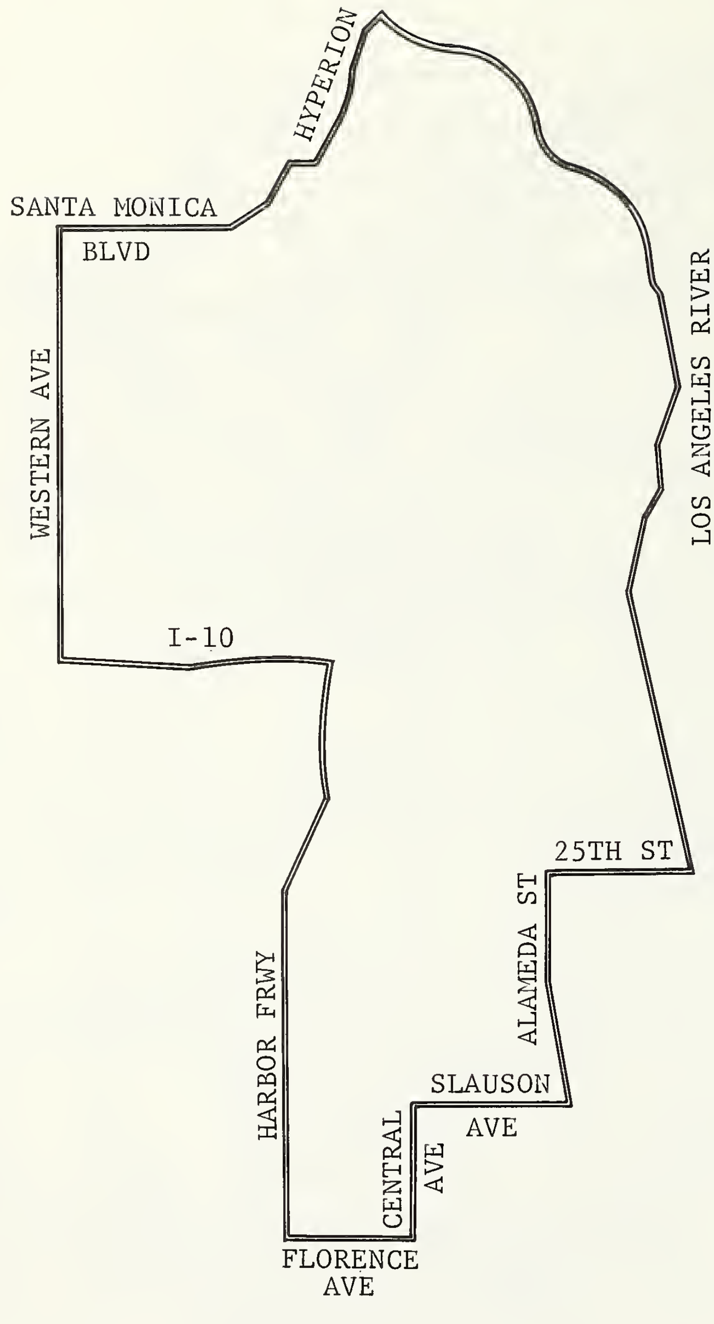


FIGURE 3-13 PRIMARY RANDOM ROUTE TEST AREA

TABLE 3-2 RANDOM-ROUTE TEST SEGMENTS

SEGMENT DESCRIPTION (STREET)	START	STOP	DISTANCE (APPROX. MI.)
PERIMETER OF REGIONS			32.0
OLYMPIC	WESTERN	L.A. RIVER	6.5
3RD STREET	WESTERN	L.A. RIVER	6.0
BEVERLY/SILVERLAKE BLVD	WESTERN	I-5	5.0
HOLLYWOOD FREEWAY	SANTA MONICA BLVD	L.A. RIVER	6.0
VERMONT AVE.	SANTA MONICA BLVD	SANTA MONICA FRWY	4.5
ALVARADO ST.	SANTA MONICA FRWY	L.A. RIVER	6.5
HARBOR FRWY	SANTA MONICA FRWY	L.A. RIVER	4.5
HILL ST.	SANTA BARBARA AVE.	PASADENA FRWY	5.5
VERNON AVE.	HARBOR FRWY	ALAMEDA ST.	3.0
MAIN/SAN PEDRO	FLORENCE AVE.	TEMPLE ST.	6.5
SLAUSON AVE.	HARBOR FRWY	CENTRAL AVE.	2.0
CENTRAL AVE.	SLAUSON AVE.	CENTRAL AVE.	5.5
ALAMEDA/N. SPRING	24TH ST.	L.A. RIVER	5.5
RIVERSIDE DR./STADIUM WAY	HYPERION	PASEDENA FRWY	5.0
		TOTAL	104.0 miles

TABLE 3-3 FREEWAY ROUTES SEGMENTS

ROUTE	TERMINAL POINTS (1)	TERMINAL POINTS (2)		DISTANCE (APPROX. MI.)
INTERSTATE 5 (N)	PASEDENA FRWY	VENTURA FRWY		7.0
HOLLYWOOD FRWY (101 N)	PASEDENA	VENTURA FRWY		10.0
INTERSTATE 10 (E)	HARBOR FRWY	HIWAY 39		20.0
INTERSTATE 10 (W)	HARBOR FRWY	SANTA MONICA		13.5
LONG BEACH FRWY (S)	I-10	OCEAN BLVD.		21.0
INTERSTATE 405	WILSHIRE	HARBOR FRWY		18.5
			TOTAL	90.0

possible. The "standard" test segment was also run at the end of the day to verify the results recorded.

After the "standard" test segment verification, each test run consisted of the complete test route, route segments, or other segments. Each segment was labeled as a Run Number and was identified on the log sheet with appropriate start points, end points, and event markers (checkpoints). Collection of the test data for each segment or route was conducted as described in the following paragraph.

The initialization process involved entering and recording of all header information. The operator would next depress the "Start Recording" key and the vehicle driver would proceed to traverse the specified route. In the survey mode, the vehicle equipment would automatically poll the system at designated intervals of 50 feet. At each poll, the appropriate time coincident data would be determined by the DAS and recorded on the cassette. As a checkpoint was approached, the test director informed the test operator who would, upon nearing the mark, depress the "Checkpoint" (event marker) key and then key stroke the appropriate number. When the vehicle actually passed the checkpoint, the operator would depress the "Send Message" key, causing a data record and the event marker code to be recorded on the cassette. If, during the test run, the cassette became full, a bell on the CRT would sound and thereby provide adequate time for the operator to load another cassette on the unused cassette drive.

All data recorded were retained and processed. Any adjustments made to the DAS between runs was logged and made a part of the test results. In the event of a human error such as a wrong turn or a wrong event, the operator would depress the "Event Error", xx, "Send Message" sequence. The nature of the error would then be described in the data

log. The occurrence of an "Event Error" on tape then served to identify, during off-line data processing, that an error was present. This allowed for recovery of all previously recorded data and continuation of the test run. Optionally the test director could "halt" all measurements, reposition the test vehicle to a selected location, and initiate recording by depressing the "Start Recording" key.

The test procedure utilized in problem areas was essentially the same except for the fact that a more detailed description of the surrounding environment was recorded on the log sheet.

Test data log sheets were prepared individually for each run. A map of the test area with route and event points clearly identified was provided with each log sheet.

A summary of the test procedure is shown in the flow diagram in Figure 3-14.

3.3.2 Special Testing Procedures

Special testing procedures involved the following:

- Different base station sites
- Different baud rates
- Different antenna polarizations.

3.3.2.1 Different Base Station Sites. Initially, testing was to be conducted utilizing only one base station site. However, after a number of tests had been completed, it became apparent that measurements from other selected sites would be desirable. As a result, tests were accomplished from four different base station sites. Tests were conducted on selected test routes using each of the base station locations. The results obtained from these tests were categorized based on the base station location. The four locations chosen were:

1. The United California Bank Building at Figuero and Wilshire in downtown Los Angeles

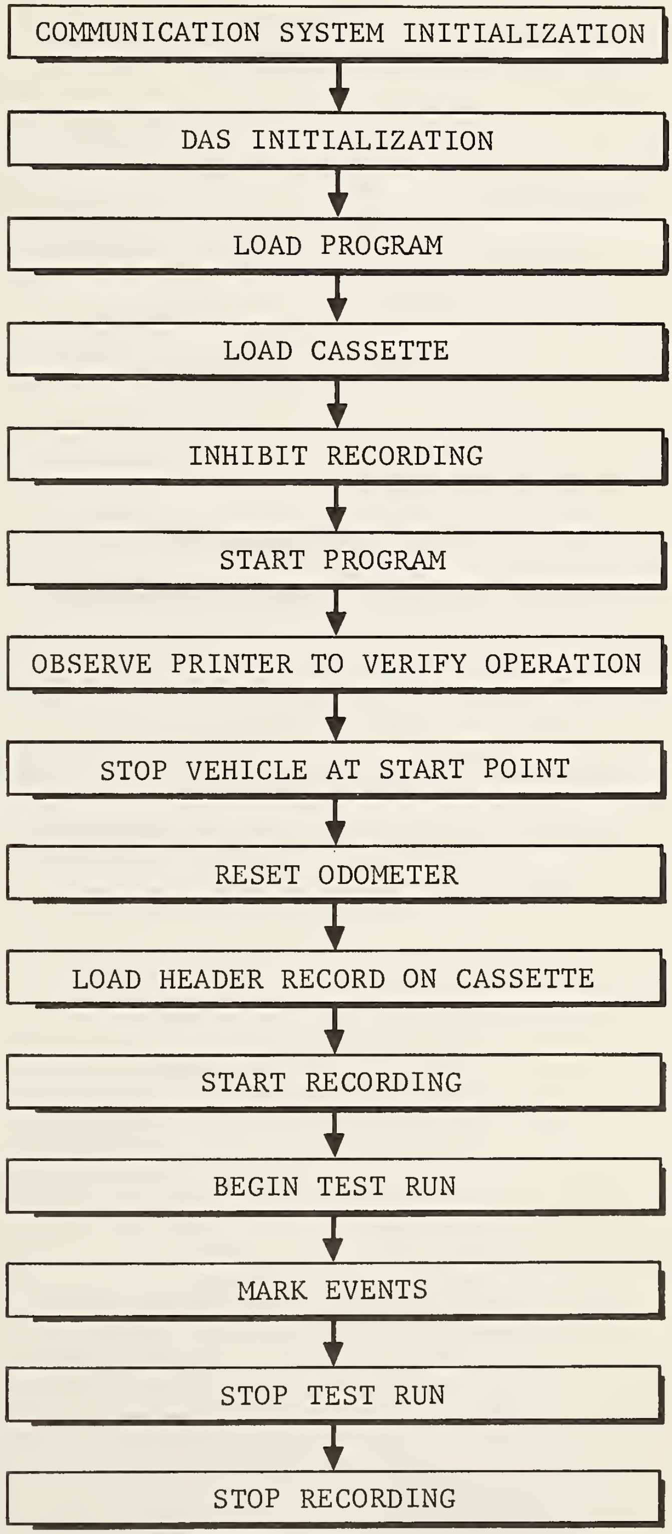


FIGURE 3-14 COMMUNICATION SURVEY TEST PROCEDURES

2. The KJOI building in Hollywood Hills

3. The present SCRTD site in Verdugo

4. Flint Peak in the foothills of the San Gabriel Mountains.

3.3.2.2 Baud Rates. In theory the probability of bit errors increases as the baud rate increases because the energy per bit decreases as given by the expression

$$E_B = P_S T_B$$

where E_B = energy per bit

P_S = received signal power

T_B = bit period which is inversely proportional to the baud rate.

In addition to this factor, the probability of multiple bit errors being produced by a fast fade increases as the bit period decreases. Consequently, there are at least two different mechanisms which tend to lower the throughput as the baud rate is increased. Utilization of unmodified voice-type radios where the data is applied to the microphone input limit the range over which the baud rate may vary to approximately 300-2400 baud. In practice, however, the baud rate is usually limited to values lying well within this range.

Special tests were conducted to study the effects of changing the baud rate on throughput, keeping all other conditions the same to the extent possible. The three baud rates at which tests were conducted were 1000, 1500, and 1800.

3.3.2.3 Polarization. There is indication in the literature (Reference 2) that, in a fading multipath environment, circularly polarized antennas may reduce the overall magnitude of fading. To study this aspect as it pertains to 800 MHz, it was decided to use the polarization of the antenna system as an independent variable and study the effects of different antenna polarization on the occurrence and depth of

fast fades.

Combinations of vertical and circularly polarized antennas were utilized and the certain specified test runs were repeated, keeping other parameters, to the extent possible, the same. The data collected from these tests were subsequently analyzed.

3.4 Data Reduction and Analysis

The reduction and analysis performed on the data are considered separately.

3.4.1 Reduction

To insure that the measurement, collection, and preservation of the data was achieved in a logical and efficient manner, the sequence of events as described and shown in Figure 3-14 was strictly adhered to. The data reduction algorithms were used in order to reduce the data into a form that would facilitate their use in the different analyses performed. The data reduction algorithms included those that classified and summarized each route segment, each route, and each group of tests by providing the following information:

1. Total number of messages attempted
2. Number of good responses (successful round trips with no errors)
3. Percentage throughput
4. Number of uplink errors
5. Number of downlink errors
6. Number of undetected message errors
7. The S/N corresponding to Items 4, 5 and/or 6
8. Code distribution for 4, 5, and/or 6
9. Identification of route segments which failed the 0.1 mile throughput requirement by number of feet from the closest event marker

10. Total cumulative length of each segment failing 0.1 mile throughput requirement

11. Vehicle incremental speed based on time and odometer data at points of error.

A sample printout of the reduced data is shown in Figure 3-15.

3.4.2 Data Analysis

As can be seen from Figure 3-15, some of the analysis pertaining to system performance parameters can be obtained directly. These include throughput and undetected message errors. The other reduced data served the supplemental function of identifying the types of errors and the conditions present when the errors occurred.

3.4.2.1 Profiles. A primary end product of the reduction program is the characterization of route profiles for all routes. The route profile printout of reduced data shows the behavior of the system parameters including signal level in dBm, noise level in dBm, S/N in dB, peak fade in dB, throughput over a 0.1 mile segment, and the presence, if any, of errors and also the type of errors. This, therefore, forms an ideal data base of pertinent information that characterizes any route in increments of 50 feet in the direction of travel along the route.

The route characterization can also be viewed as a map showing the response (good/error/type of error), S/N, and throughput along the length of a route segment such as in Figure 3-16.

3.4.2.2 Large Scale Variations. In an attempt to study the effect of the mean received signal strength over distance along the route, sections of routes representing different conditions of terrain were developed. These plots clearly show the effects of different types of topology upon the received signal strength. For purposes of analysis, the topology was divided into three categories as follows:

RUN NO	DATE	TIME	REC MODE	FT/POLL	SC/POLL	FT/PULSE	BAUD RATE
6	5/12/78	13:15	1	50	0.0	2	1500

EVENT CODE	TIME HH:MM:SS	DISTANCE (FT.)	INCREMENTAL SPEED (MPH)	SIGNAL LEVEL (DBM)	NOISE LEVEL (DBM)	S/N (DB)	PEAK FADE (DB)	RESPONSE CODE	0.1 MILE THRUPUT(%)
1	13 15 13	50	0.0	-76.9	-119.0	42.1	8.3	0	0.0
0	13 15 17	100	8.3	-82.2	-118.3	36.1	12.8	0	0.0
0	13 15 20	150	11.8	-74.9	-118.7	43.8	5.0	0	0.0
0	13 15 22	200	14.8	-76.1	-118.7	42.6	29.5	0	0.0
0	13 15 24	250	15.5	-70.4	-118.3	47.9	6.7	0	0.0
0	13 15 26	300	17.0	-66.2	-118.7	52.5	2.5	0	100.0
0	13 15 28	350	20.1	-74.5	-118.7	44.1	17.4	0	100.0
0	13 15 30	400	20.1	-71.6	-118.7	47.0	19.6	0	100.0
0	13 15 31	450	21.3	-68.7	-118.7	50.0	19.1	0	100.0
0	13 15 33	500	22.7	-73.3	-118.3	45.0	28.3	0	100.0
0	13 15 34	550	22.7	-72.5	-118.7	46.1	14.0	0	100.0
0	13 15 36	600	22.7	-64.5	-118.3	53.8	2.7	0	100.0
0	13 15 38	650	18.9	-70.1	-118.3	48.2	7.6	0	100.0
0	13 15 40	700	12.6	-75.2	-118.7	43.5	3.4	0	100.0
0	13 15 46	750	6.7	-70.7	-118.7	48.0	23.4	0	100.0
0	13 15 48	800	14.8	-66.2	-118.7	52.5	3.4	0	100.0
0	13 15 50	850	18.9	-69.0	-118.3	49.3	13.7	0	100.0
0	13 15 51	900	21.3	-75.6	-118.7	43.1	17.3	0	100.0
0	13 15 53	950	22.7	-72.0	-118.7	46.7	10.2	0	100.0
0	13 15 54	1000	22.7	-71.4	-118.7	47.3	6.6	0	100.0
0	13 15 56	1050	24.4	-69.0	-118.7	49.6	4.5	0	100.0
0	13 15 57	1100	22.7	-74.9	-118.7	43.8	23.0	0	100.0
0	13 15 59	1150	24.4	-68.7	-118.7	49.9	9.7	0	100.0
0	13 16 0	1200	24.4	-69.0	-118.7	49.6	4.0	0	100.0
0	13 16 1	1250	22.7	-70.2	-118.3	48.1	9.6	0	100.0
0	13 16 3	1300	22.7	-71.3	-118.7	47.3	18.5	0	100.0
0	13 16 4	1350	22.7	-73.8	-118.7	44.9	26.1	0	100.0
0	13 16 6	1400	20.1	-71.3	-118.7	47.3	7.7	0	100.0
0	13 16 8	1450	18.9	-76.4	-118.7	42.2	29.2	0	100.0
0	13 16 10	1500	16.2	-71.6	-118.3	46.8	10.5	0	100.0
0	13 16 14	1550	8.1	-71.5	-118.3	46.8	4.8	0	100.0
0	13 16 50	1600	0.9	-64.8	-119.0	54.2	4.6	0	100.0
0	13 16 53	1650	14.8	-76.1	-118.3	42.3	13.1	0	100.0
0	13 16 55	1700	17.9	-69.4	-118.7	49.3	30.5	0	100.0
0	13 16 56	1750	21.3	-78.6	-118.7	40.1	15.7	0	100.0
0	13 16 58	1800	20.1	-65.4	-118.7	53.2	7.5	0	100.0
0	13 16 59	1850	22.7	-68.6	-118.3	49.7	6.1	0	90.9
0	13 17 1	1900	24.4	-69.6	-118.7	49.0	9.5	0	90.9
0	13 17 2	1950	24.4	-73.3	-118.7	45.4	15.9	0	90.9
0	13 17 4	2000	24.4	-75.3	-118.7	43.4	10.9	0	90.9
0	13 17 5	2050	24.4	-76.4	-118.7	42.2	12.8	0	90.9
0	13 17 6	2100	24.4	-74.2	-118.0	43.8	30.8	3	90.9

FIGURE 3-15 SAMPLE PRINTOUT OF REDUCED DATA

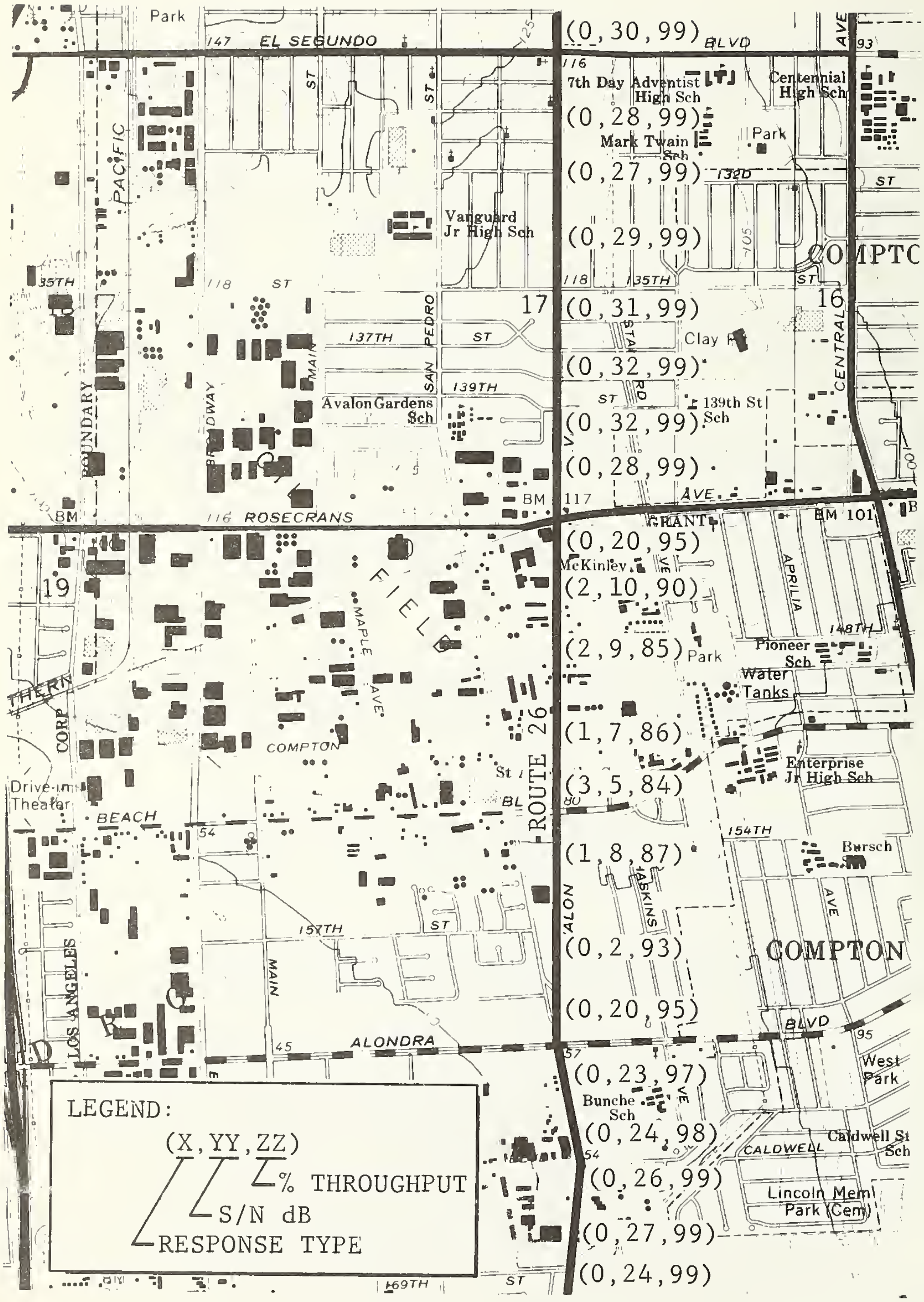


FIGURE 3-16 ROUTE 29 SEGMENT CONTOUR CHARACTERIZATION EXAMPLE

- hilly terrain, e.g., the northern leg of Route 7
- medium build-up, e.g., the central part of Route 83
- urban area, e.g., the southern leg of Route 29.

The results of this analysis are discussed in detail in Section 4.3.

3.4.2.3 Fast Fade. The study of the effects of fast fade is probably one of the most critical aspects of this study. For each of the route segments that was used in developing large-scale-variation plots, corresponding plots of small scale variations or fast fade were also developed. These plots, shown in Section 4, signify the probability associated with the observance of a specified level of peak fade.

3.4.2.4 Cross-Canyon and Down-Canyon Characteristics. In addition to the observation of fast fades in different topographical sections, the fast fade in the heart of the downtown CBD was also examined relative to "cross-canyon" characteristics. The term "cross-canyon" refers to streets in a highrise section of a city that run at right angles to the "line of sight" to the base station. The tall buildings in essence form a physical canyon. The term "down-canyon" refers to streets in a highrise area of a city that run parallel to the "line of sight" to the base station. Figures 3-17 and 3-18 show the results obtained. The results are discussed in detail in Section 4.

3.4.2.5 Effect of Different Base Station Sites. In the interest of obtaining better coverage and higher throughput on each route, the results obtained through the use of different base station sites were examined relative to communications coverage of the designated routes. In particular, Route 83, which presented problems of low throughput in the Santa Monica area when the UCB building was the base station site, was examined with the base station moved to KJOI in Hollywood Hills. The effect of the change in the site on the throughput coverage, signal strength, and fast

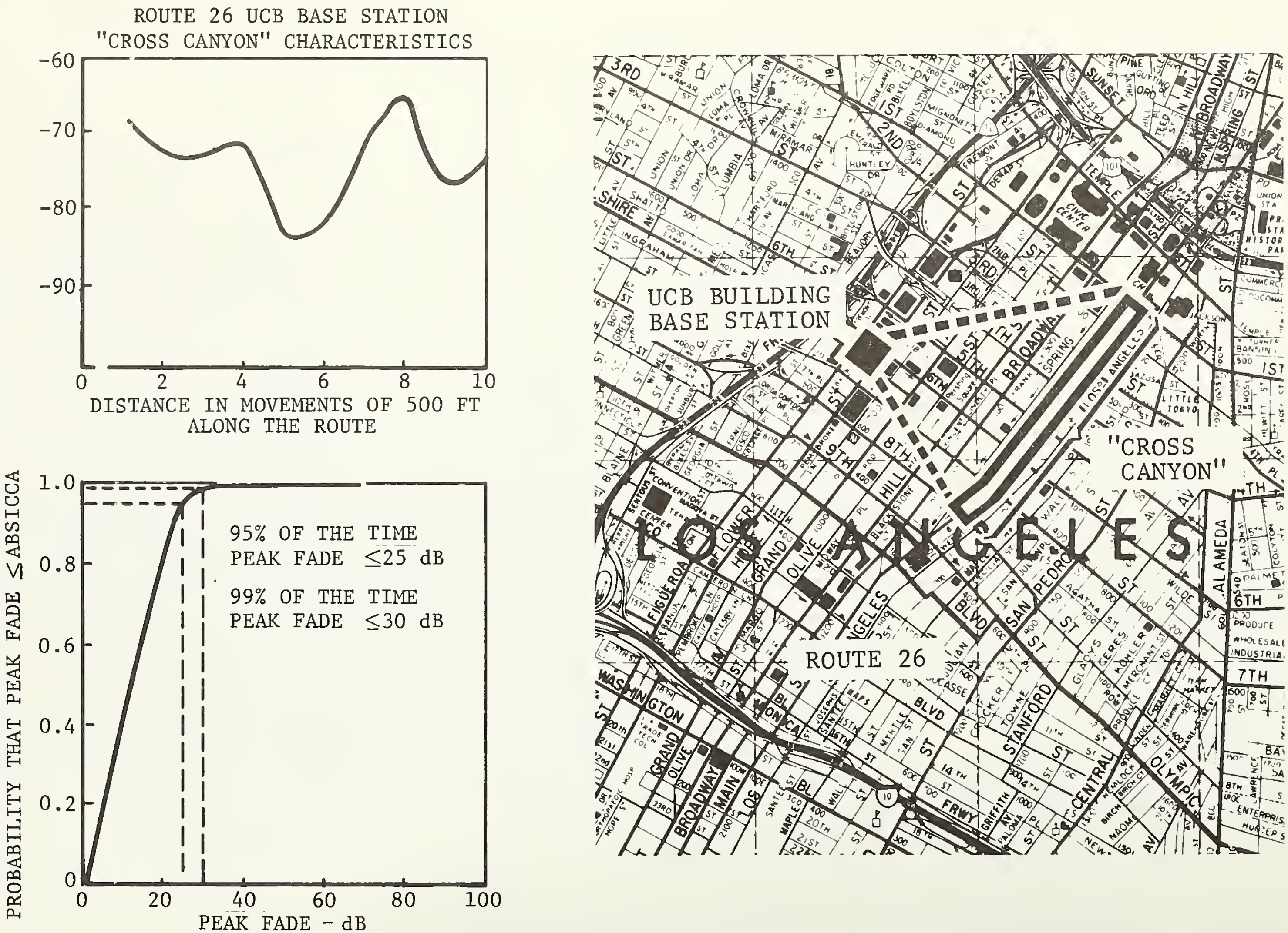
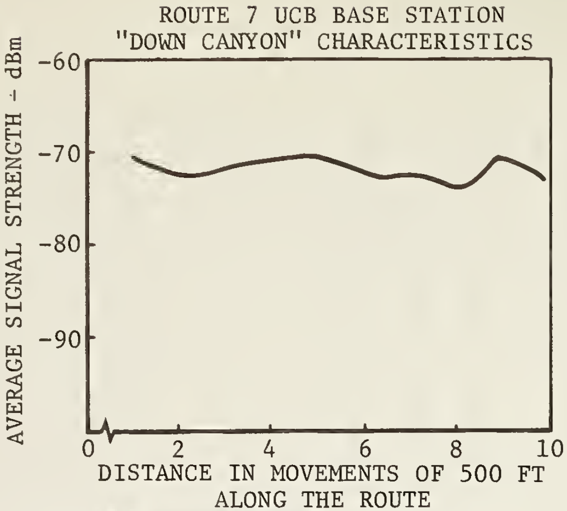
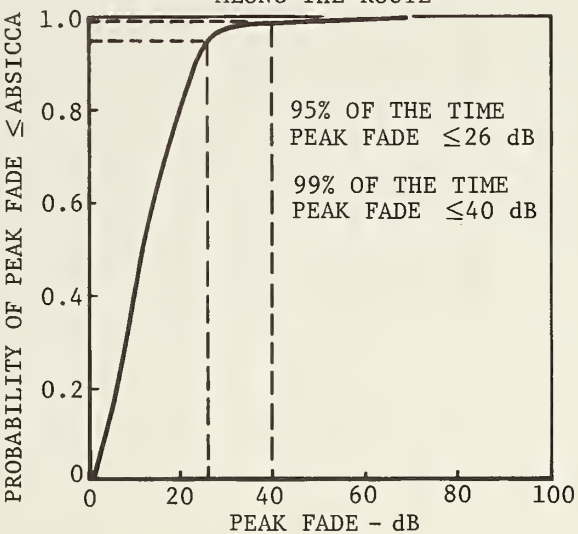


FIGURE 3-17 CROSS-CANYON CHARACTERIZATION EXAMPLE





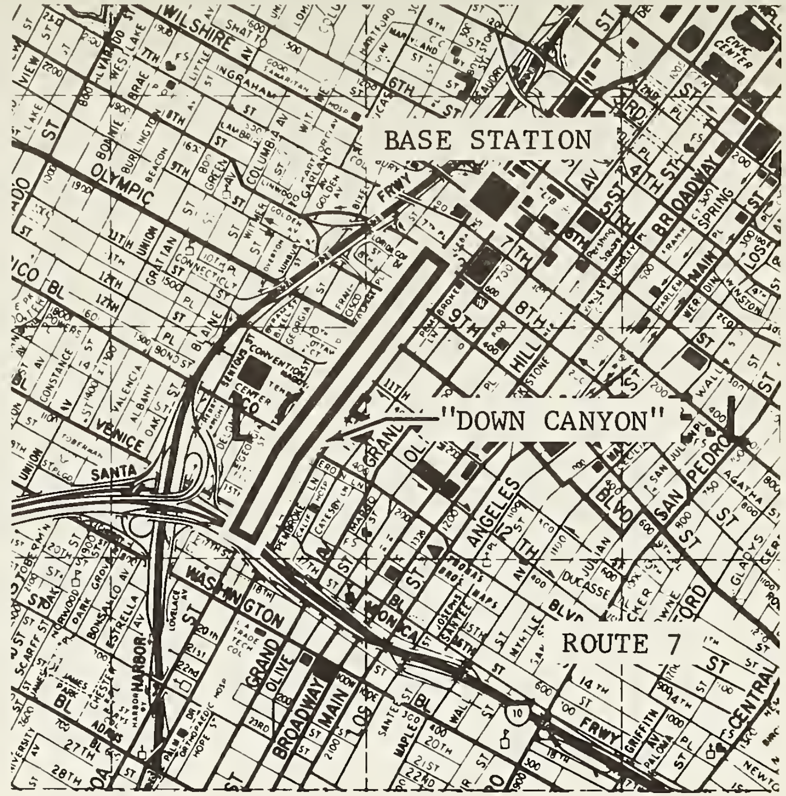


FIGURE 3-18 DOWN-CANYON CHARACTERISTICS

fade was analyzed. Results of these tests and analyses are discussed in detail in Section 4.

3.4.2.6 Effects of Antenna Polarizations. To study the effects of combinations of different antenna polarizations, tests were conducted on a segment of Route 7 (between event markers 19 and 22) using the UCB building as the base station. The first phase of the study involved the use of a vertically polarized antenna at the base station and on the test vehicle. An analysis of the probability of peak fade occurrences was conducted on the resulting test data. The next tests involved repeating the tests with both antennas circularly polarized. A similar analysis was conducted. The results of these analyses are discussed in Section 4.

3.4.2.7 Effect of Changing Baud Rate. A study of the effects of different baud rates on the throughput was conducted on Route 7 using the UCB building as the base station with both antennas vertically polarized. Polling was conducted every 50 feet. The baud rates used were 1000 BPS, 1500 BPS, and 1800 BPS. A discussion of the test results is contained in Section 4.

3.4.2.8 Error Mechanism. To study the mechanism creating the errors that were observed, a sample of 100 such errors was analyzed in order to identify the possible source of the errors. Results are discussed in Section 4.

SECTION 4

RESULTS

4.1 Route Profiles

The analysis of route profiles involved two approaches. The first approach involved development of a computer program to reduce the raw data collected in the survey into a form that exhibited the characterization of the route or segment under consideration.

A sample printout of the results produced by this program is shown in Figure 3-15. The first column identifies selected reference location points along the route. These points are indicated by event marker numbers and provide a measure of the approximate distance of each polling point from a reference location in terms of the vehicle's location along the route. The second column indicates the elapsed time since the start of the run in hours/minutes/seconds rounded off to the nearest tenth of a second. The third column indicates the distance travelled in feet since the last event code. The fourth column indicates the incremental speed of the vehicle during the previous polling interval. The fifth column indicates the average level of the signal samples received by the TSC receiver during the received message interval. The sixth column indicates the average level of the noise samples as measured by the TSC receiver during the interval between polls. The seventh column indicates the difference in dB between the values shown in columns five and six and hence is the value of the S/N in dB. The eighth column contains the peak deviation, in dB, from the mean value of the signal during the message interval and is, therefore, the peak fade level during the transmission. The ninth column indicates the type of response (or error). The coding used is explained as follows:

0 - Good response (no message error)

1 - Good response (undetected message error)

2 - Uplink error (base-to-vehicle)

3 - Downlink error (vehicle-to-base).

The last column indicates the percentage throughput based on all transmissions approximately 250 feet on either side of the sample location. The average was performed on five samples before and five samples after, plus the sample being considered. Thus, this column closely approximates 0.1 mile throughput. This column indicates areas where the throughput may fall below the 75 percent specification.

The second analytical approach was applied to selected route segments to provide a graphic representation, with the help of maps showing the essential topographical features in the background, and measures of throughput, signal level and peak fade, averaged over 500 foot segments. Figure 3-16 contains a graphic representation of this analysis.

4.2 Large Scale Variations

The route segments were categorized by the type of terrain. For purposes of analysis, three categories were defined as follows:

1. Hilly terrain - northern leg of Route 7
2. Medium build-up - central part of Route 83
3. Urban area - southern leg of Route 29.

Each of these segments was analyzed for the behavior of the mean signal strength as a function of distance.

4.2.1 Hilly Terrain

The northern leg of Route 7, the area around Eagle Rock, was chosen to represent the hilly terrain. From Figure 4-1, which shows this section of Route 7, it can be observed that Route 7 passes around the Eagle Rock

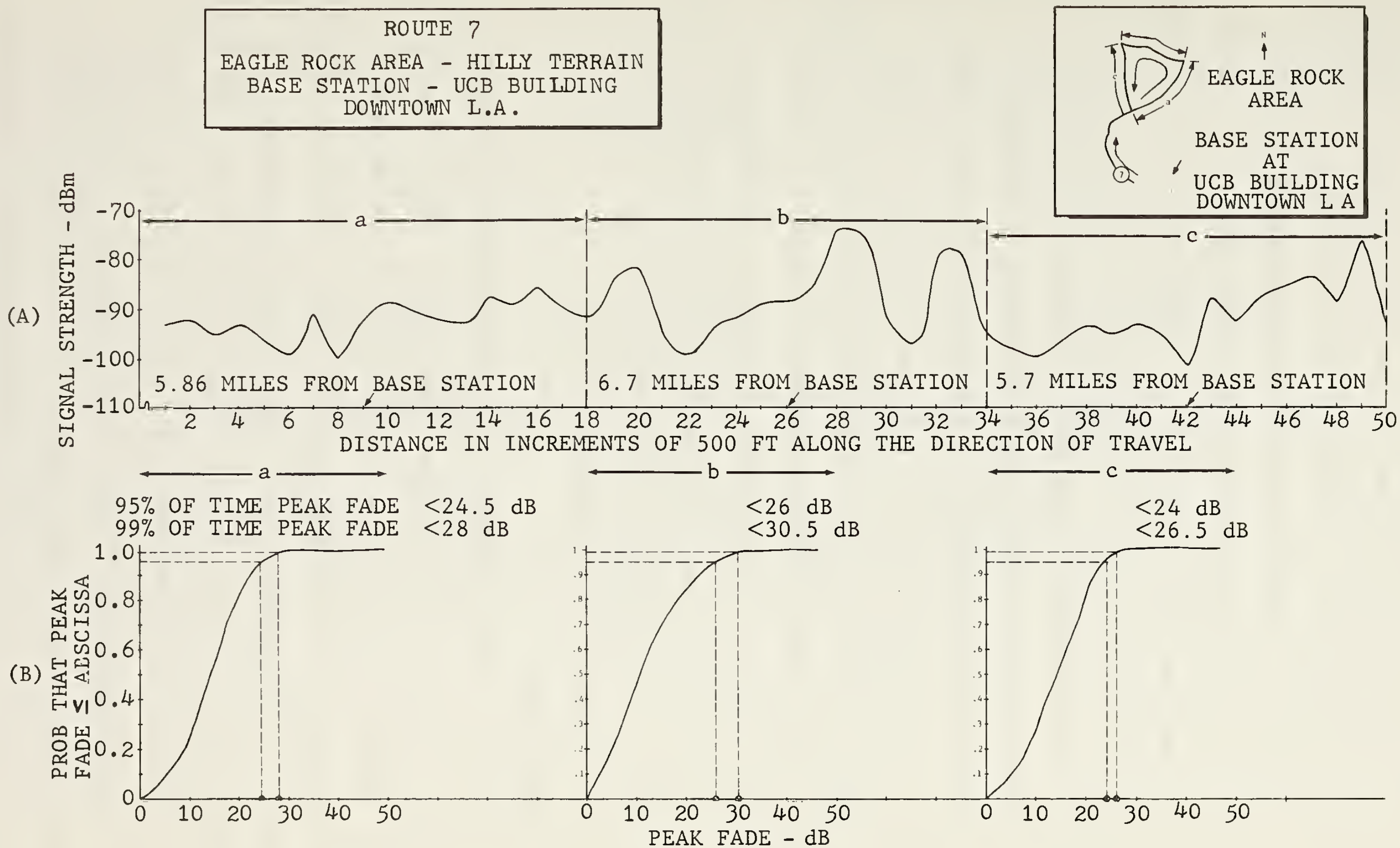


FIGURE 4-1 HILLY TERRAIN

hills eastward (Section "a") behind a hill, shadowed from the base station at the UCB building (Section "b"), and turns around the other side of the hill (Section "c"). Section b is the primary region of interest. Figure 4.1A illustrates the mean received signal level in dBm along the three sections of the northern leg of Route 7. It can be seen that the received signal strength shows a variation of about 15 dBm, dropping from -85.5 dBm to -100 dBm over Section a. In Section b, the segment of the route shadowed by the hill, the variation of received signal strength is larger, from a minimum of -98 dBm to a maximum of -74 dBm, a 24 dB change. The reason for this behavior can be clearly attributed to the shadowing effects of the Eagle Rock hills. Along Section c, where the route turns around and again heads southward, the behavior of signal strength would be expected to display an increase with increasing distance along the route (equivalent to decreasing distance from the actual base station site). The results do exhibit this characteristic. The standard deviations computed for Sections a, b, and c were 3.6 dB, 7.6 dB, and 6.36 respectively.

4.2.2 Medium Build-Up

To represent a medium build-up area, the central part of Route 83, represented in Figure 4-2, was chosen. This area is characterized by a gradual gradient with the part of Route 83 south of Hollywood Hills flanked on either side by buildings that are three to four stories high. The behavior of the received signal strength is fairly predictable as it decreases with increasing distance along the route from the UCB base station. The variations observed are the of the order of 5-10 dB with the most drastic variations being observed in Section c. These are attributed to multipath effects, generated by the buildings flanking the route on either side. The standard deviations computed for Sections

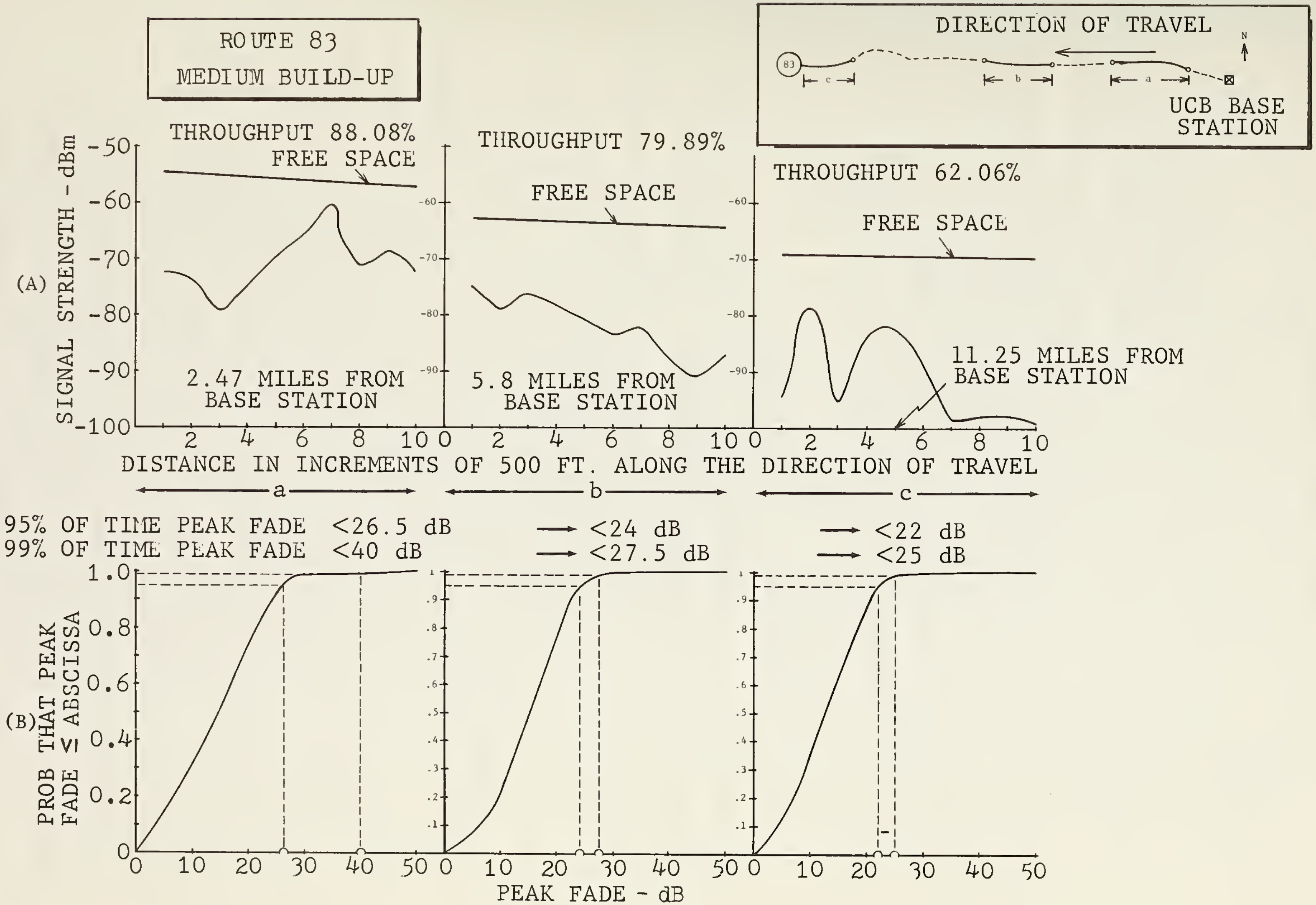


FIGURE 4-2 MEDIUM BUILD-UP FROM UCB BUILDING

a, b, and c are 5.2 dB, 5.2 dB, and 9.6 dB respectively.

4.2.3 Urban Area

The route segment selected as representative of a typical urban mass area was the southern leg of Route 29 which is characterized by many buildings which are one or two stories high flanking the route on either side. The behavior of the mean received signal when driving southward on this segment was found to exhibit a very gradual decreasing signal level with increasing distance along the route from the base station at the UCB building in the downtown CBD, as can be seen from Figure 4-3. The standard deviation computed for Sections a, b, and c are 1.5 dB, 3.5 dB, and 2.2 dB respectively.

4.3 Small Scale Variations

The phenomenon of fast fade that appears to be critical to digital data communication at UHF frequencies was analyzed for different topographical sections of the SCRTD routes which were also analyzed in terms of the behavior of the mean received signal strength. The extent of fast fade was analyzed by measuring the peak fade at each poll and plotting the peak fade against its frequency of occurrence to determine the extent of peak fade that could be expected under different topographical conditions, both 95 percent of the time and 99 percent of the time. The two levels of peak fade were determined for each section of the three topographically different routes. The frequency of occurrence versus peak fade characteristics were plotted. The peak fade probability presented in this study is based on a 150 millisecond word length. Obviously, a longer or shorter word length would alter the results.

The peak fade at the 95 percent level was computed by observing the peak fade associated with each poll along the run for the segments under consideration and determining a frequency of occurrence count

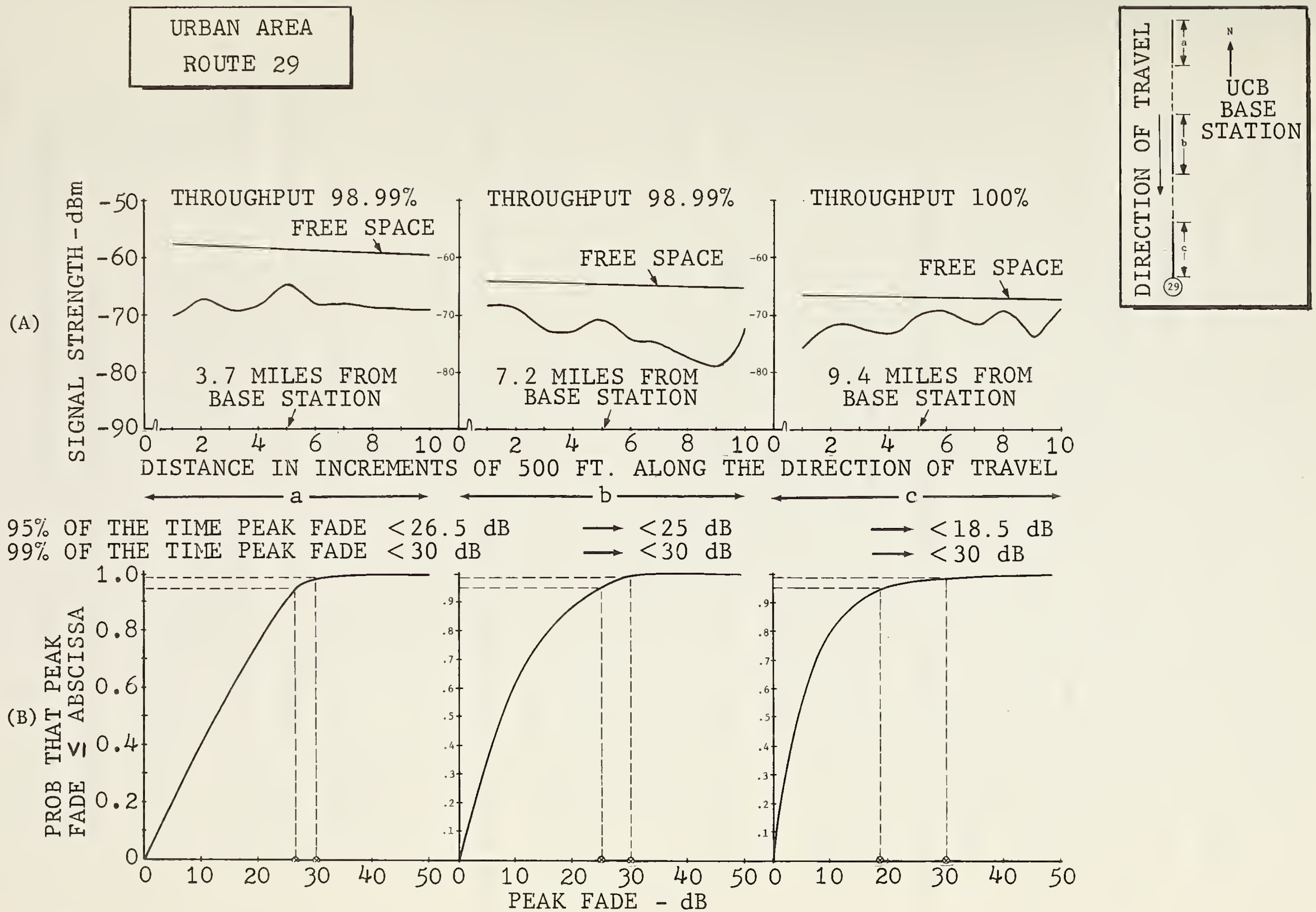


FIGURE 4-3 URBAN AREA

where the number of occurrences of peak fade less than or equal to a specified value was divided by the total number of polls considered in the segment. This was subsequently interpreted as a probability occurrence. For purposes of attributing a level of peak fade to any section of the route, the 95 percent figure would appear to be more realistic and reliable than the 99 percent figure, as the sample size of each segment was only 100 polls.

4.3.1 Hilly Terrain

The peak fade probability curve for hilly terrain areas is shown in Figure 4-1B. As can be seen, the peak fade in the two sections that skirt the hills of Eagle Rock is about 24 dB at the 95 percent level; however, in the region that is shadowed by Eagle Rock, the peak fade at the 95 percent level is 26 dB. This slight increase in the 95 percent level of peak fade can be attributed directly to the "blocking" effects of the Eagle Rock Hills.

4.3.2 Medium Build-Up

As shown in Figure 4-2B, the peak fade characterization in the medium build-up area is more uniform than that associated with the hilly terrain. A 95 percent probability of about 25 dB peak fade was observed.

4.3.3 Urban Area

As shown in Figure 4-3B, the peak fade characterization in the urban area is almost the same as that for the medium build-up, with a gradual increase with decreasing distance from the base station along the length of the route. The peak fade at the 95 percent probability level is approximately 20-25 dB.

4.3.4 Down-Canyon and Cross-Canyon Characteristics

To study the down-canyon characteristics, the UCB building was used as the base station and the section of Route 7 between event markers

23 and 25 was selected to study the down-canyon effects. Figure 3-18 shows the behavior of the mean received signal in this section of the route and also the probability associated with observing different levels of peak fade.

It can be observed that the mean received signal strength varies between -70 dBm and -74 dBm, less than 5 dB change. The peak fade probability graph shows that 95 percent of the time the peak fade would be less than 25 dB.

The section used to study the cross-canyon characteristics was the route length between event markers 18 and 20 on Route 26 using the UCB building as the base station. The mean received signal variation over this segment showed the trend displayed in Figure 3-17 between -84 and -67 dBm as compared with the down-canyon effects on received signal strength. This section, the cross-canyon, showed greater variation in received signal strength. The peak fade corresponding to the cross-canyon characteristics showed a 95 percent probability of 25 dB also. However, this value coupled with a lower signal strength resulted in a greater degradation of the signal in the cross-canyon situation as compared with the down-canyon situation.

4.4 Base Station Sites

Route 83 will probably require two separate base stations at different sites in order to meet coverage requirements. The first site is the UCB building in downtown Los Angeles and the second base station site is at KJOI tower in the Hollywood Hills.

To compare the coverage, throughput and peak fade characteristics, the same sections of Route 83 were selected and analyzed. The results of mean signal strength, throughput, and peak fade are shown in Figures 4-2 and 4-4.

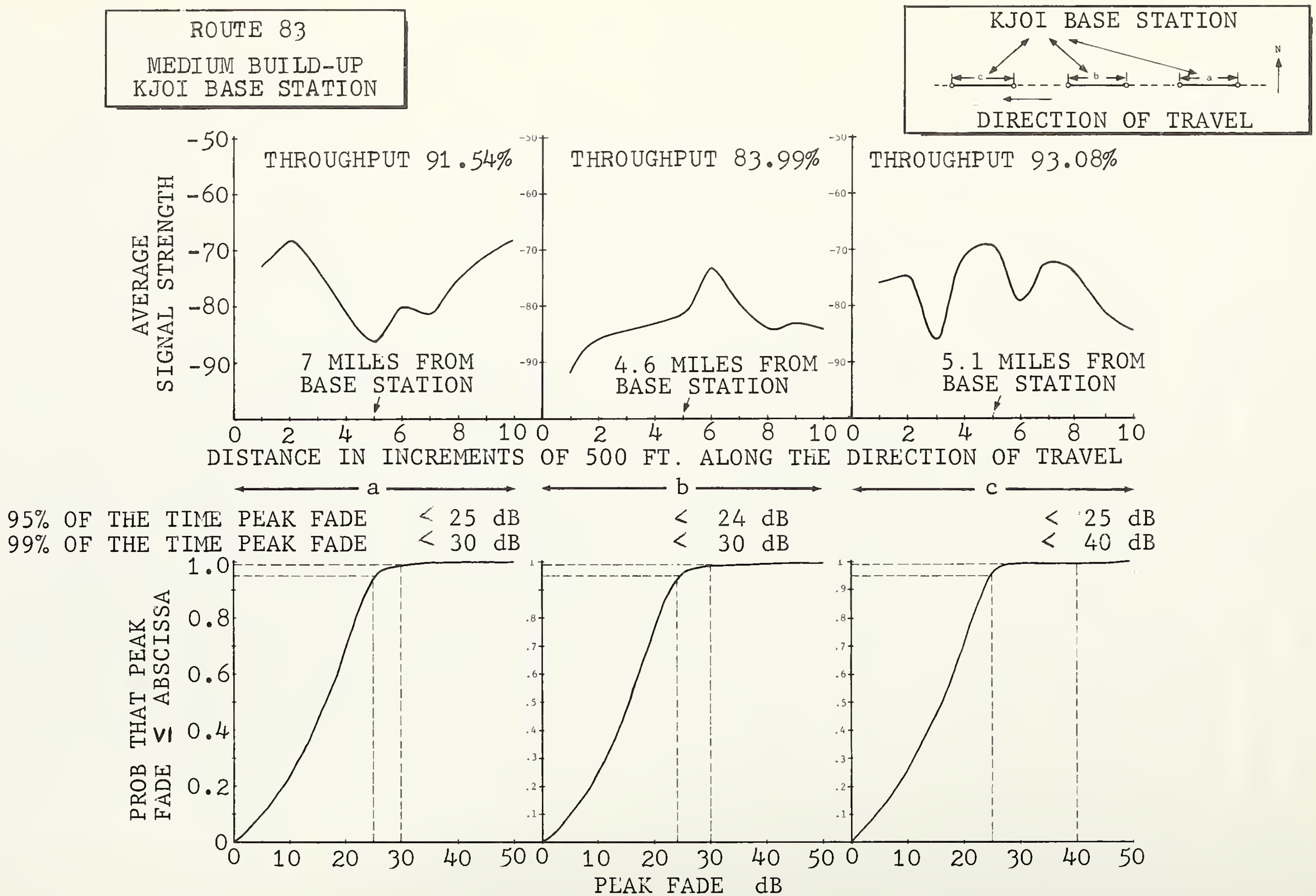


FIGURE 4-4 MEDIUM BUILD-UP FROM KJOI

It can be seen from these figures that:

a. Signal strength variations in the both cases were found to be in the region of 15 to 20 dB with the most drastic variations occurring in Section c for reasons explained earlier.

b. Throughput was, however, found to be consistently better from KJOI as compared with the UCB Bank Building.

c. Peak fade was again found to be approximately 25 dB regardless of the nature of the terrain.

Two other base station sites were utilized during the tests. These two sites were used primarily to measure the effects of hilly terrain on throughput. Temporary sites were established at the present SCRTD site at Verdugo Peak and Flint Peak to study the effects that the hilly terrain in the Eagle Rock area had on coverage of the north end of Route 7. The results of these tests were essentially the same as those described in paragraph 4.3.1.

4.5 Relationship Between Peak Fades and Probability of Errors

The following analysis was conducted to determine the level of peak fade that would have the greatest probability of generating errors. In this analysis, 3005 polls on Route 7 were considered and peak fades that occurred on each of these polls were categorized into five categories as follows: (1) 0 to 10 dB, (2) 10 to 20 dB, (3) 20 to 30 dB, (4) 30 to 40 dB, and (5) 40 to 50 dB. The number of errors that occurred in each of these categories were tabulated separately.

Using these figures, two relationships were derived:

1. The probability of peak fades having values between 0 and 10 dB 10 and 20 dB, 20 and 30 dB, 30 and 40 dB, and 40 and 50 dB, respectively.

2. The probability that peak fades (pf) lie between 0 and 10 dB

is given by

$$p[0 < pf < 10] = \frac{\text{Number of polls where peak fade was between 0 \& 10 dB}}{\text{Total number of polls}}$$

(This is the marginal probability of a particular peak fade interval)

$$p[0 < pf < 10] = \frac{1400}{3500} = 0.466 \qquad (1a)$$

The probability that peak fades lie between 10 and 20 dB:

$$p[10 < pf < 20] = \frac{\text{Number of polls where peak fade was between 10 to 20 dB}}{\text{Total number of polls}}$$

$$p[10 < pf < 20] = \frac{1115}{3005} = 0.371 \qquad (1b)$$

Similarly, the probability that peak fades lie between 20 and 30 dB:

$$p[20 < pf < 30] = \frac{460}{3005} = 0.153 \qquad (1c)$$

The probability that peak fades lie between 30 and 40 dB:

$$p[30 < pf < 40] = \frac{28}{3005} = 0.009 \qquad (1d)$$

The probability that peak fade lies between 40 and 50 dB:

$$p[40 < pf < 50] = \frac{2}{3005} = 0.0007 \qquad (1e)$$

These results can be represented by the histogram shown in Figure 4-5.

2. The probability of errors occurring in these peak fade intervals was then determined by the following relationship: (This is the same as conditional probability of error given a particular peak fade interval.)

$$p[E/\text{peak fade interval}] = \frac{\text{Number of errors in the interval}}{\text{Number of peak fades in the interval}}$$

Thus, the probability of errors in the interval 0 to 10 dB:

$$p[E/0 < pf < 10] = \frac{0}{1400} = 0 \text{ where pf represents peak fade} \qquad (2a)$$

The probability of errors in the interval 10 to 20 dB:

$$p[E/10 < pf < 20] = \frac{80}{1115} = 0.0717 \qquad (2b)$$

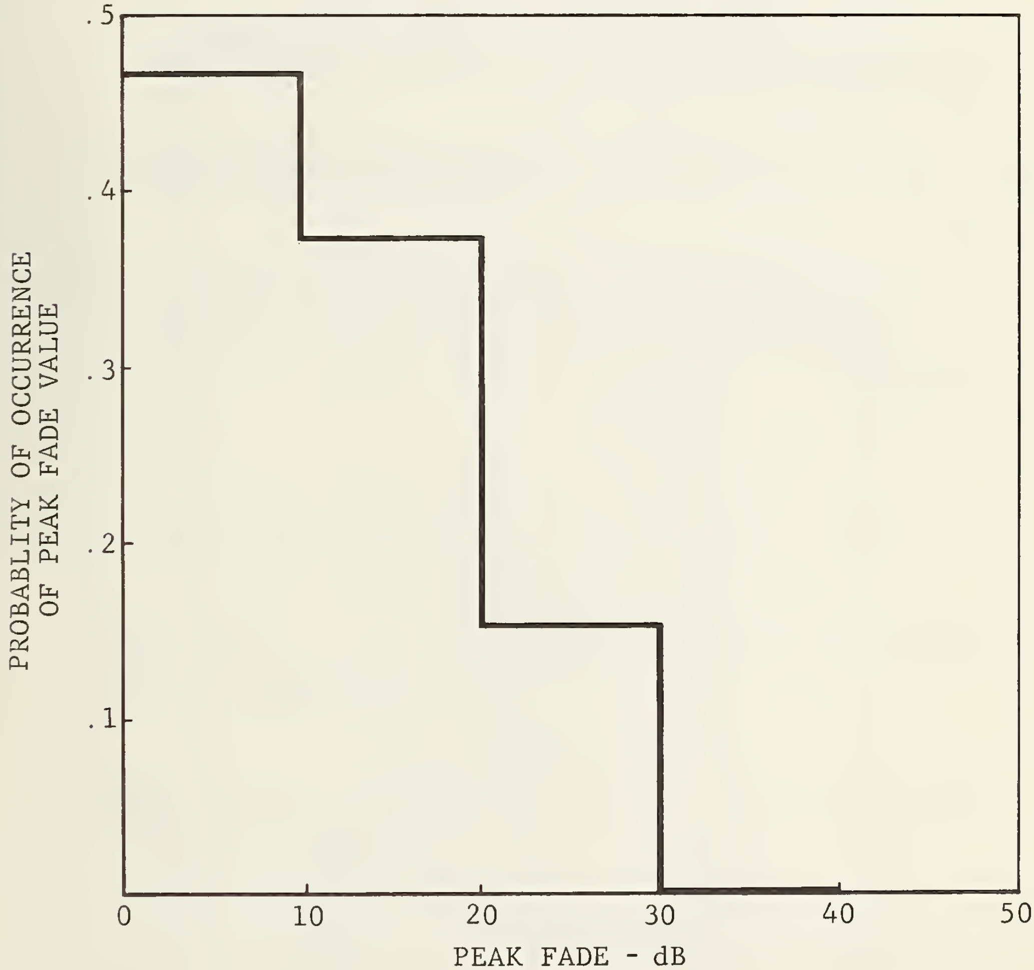


FIGURE 4-5 PEAK FADE PROBABILITIES

The probability of errors in the interval 20 to 30 dB:

$$p[E/20 < pf < 30] = \frac{76}{460} = 0.1652 \qquad (2c)$$

The probability of errors in the interval 30 to 40 dB:

$$p[E/30 < pf < 40] = \frac{10}{28} = 0.03571 \qquad (2d)$$

The probability of errors in the interval 40 to 50 dB:

$$p[E/40 < pf < 50] = \frac{0}{2} = 0 \qquad (2e)$$

These probabilities can further be represented by the histogram shown in Figure 4-6.

Finally, the two probabilities generated in Figures 4-5 and 4-6 can be combined to form the joint probabilities of errors and peak fade in a particular interval.

Thus,

$p[E,0< pf< 10]$ = Joint probability of error in the interval 0 to 10 dB peak fade = 1a x 2a = 0.

$p[E,10< pf< 20]$= Joint probability of error in the peak fade interval of 10 to 20 dB peak fade =1b x 2b = 0.371 x 0.0712 = 0.0266.

$p[E,20< pf< 30]$= Joint probability of error in the peak fade interval of 20 to 30 dB = 1c x 2c = 0.153 x 0.1652 = 0.0253.

$p[E,30< pf< 40]$= Joint probability of error in the peak fade interval 30 to 40 dB = 1d x 2d = 0.009 x 0.3571 = 0.0033.

$p[E,40< pf< 50]$= Joint probability of error in the peak fade interval 40 to 50 dB = 1e x 2e = 0.0007 x 0 = 0.

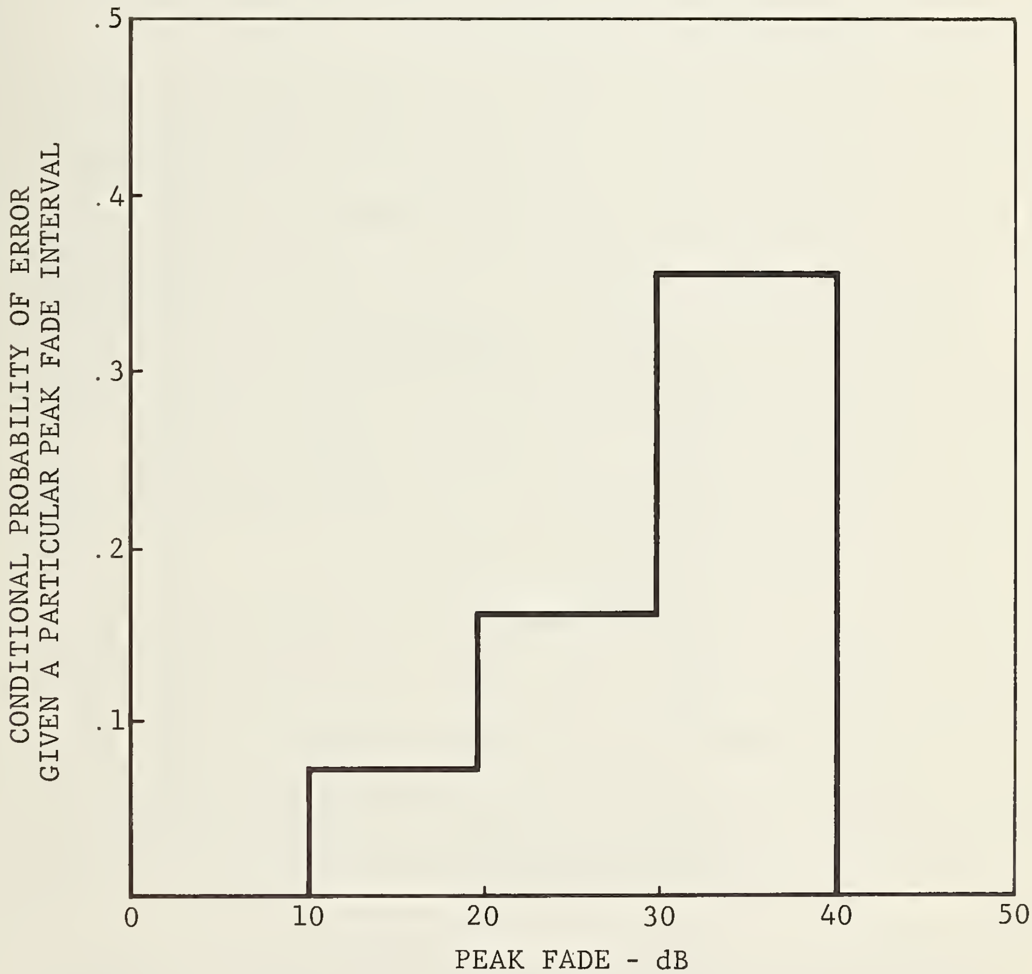


FIGURE 4-6 CONDITIONAL PROBABILITY OF ERRORS IN A GIVEN PEAK FADE INTERVAL

These probabilities can finally be plotted by the histogram shown in Figure 4-7.

4.6 Major Message Error Mechanisms

Having developed the cumulative probability of errors in any peak fade interval, we next consider the errors specifically and examine the mechanism or cause for their occurrence.

To study the source of message errors, a sample of 100 such errors from Routes 7 and 83 was taken as representative of all downlink errors. The peak fade for each of these errors was computed at the instant of peak fade and this value of S/N at the instant of peak fade was plotted as a probability of its occurrence. It turned out that 70 to 75 percent of the errors had occurred when the peak fade caused the instantaneous signal strength during the word to drop below the level where the instantaneous S/N was less than 12 dB. It was not clear what had caused the errors the remaining 25 percent of the time.

Two possible explanations for these errors are as follows. The sampling resolution (one word being sampled every 512 microseconds) did not permit the absolute minimum value of the fade to be recorded, and so an error would not necessarily be portrayed by the S/N at the measured peak fade, as the actual peak fade could be much greater than the recorded values.

Multipath effects could have caused phase distortion to the extent that errors in the word were detected. The results are shown in Figure 4-8.

4.7 Antenna Tests

Literature suggests a possibility of improved performance by using circularly polarized antennas in an urban environment. This variable was also investigated to observe its effects on fast fade. Figure 4-9 shows

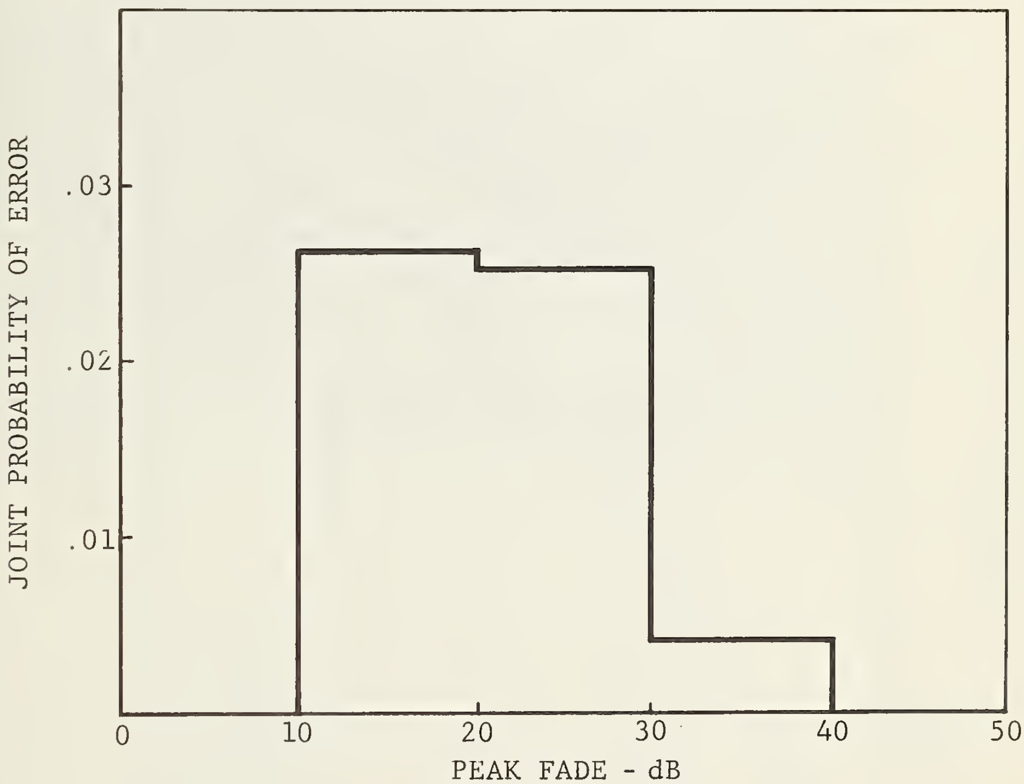


FIGURE 4-7 JOINT PROBABILITY OF ERROR IN PEAK FADE INTERVAL

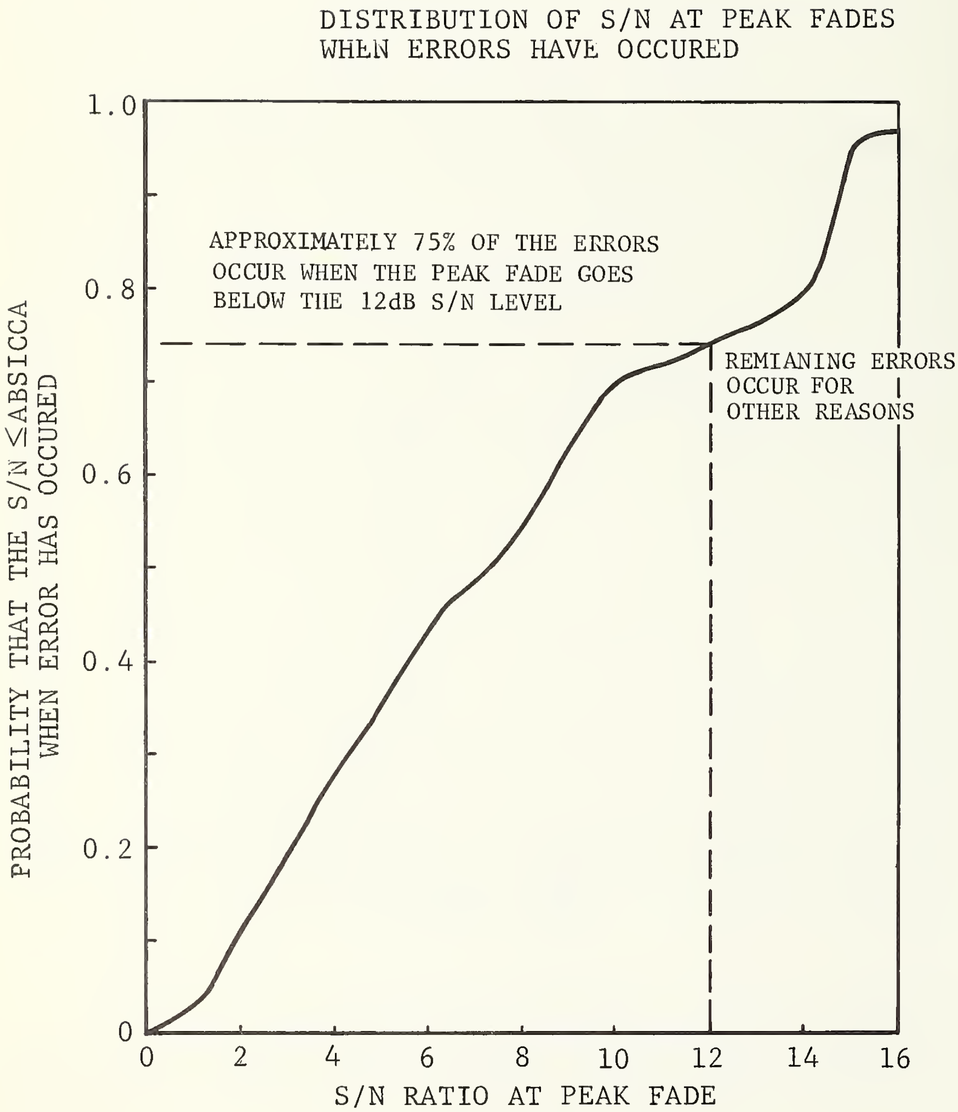
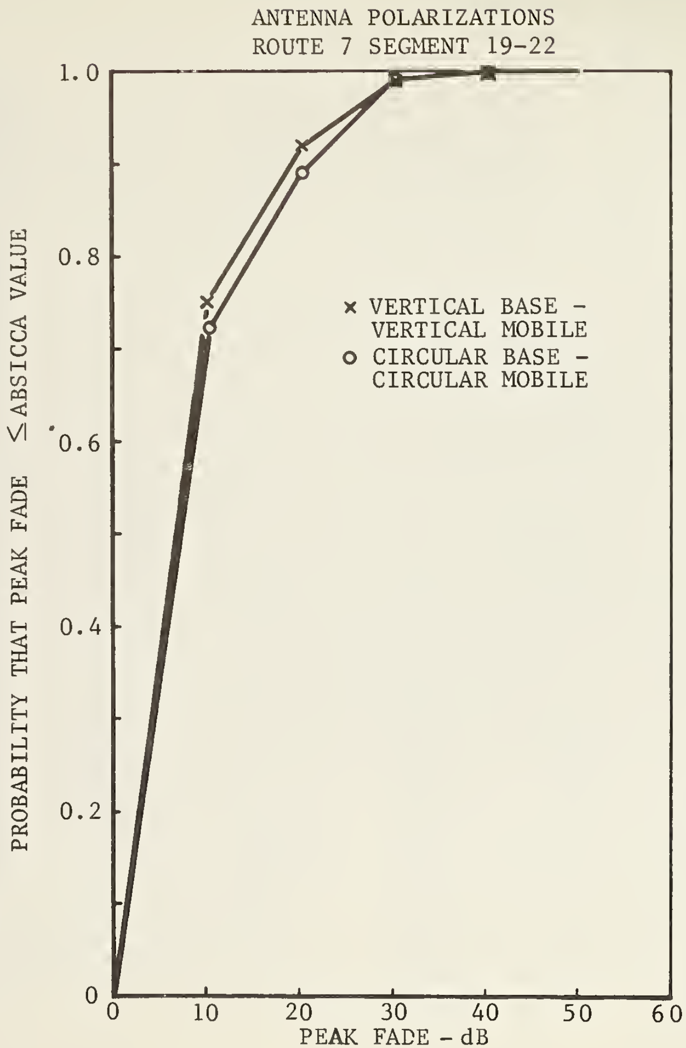


FIGURE 4-8 ERROR MACHANISM STATISTICS



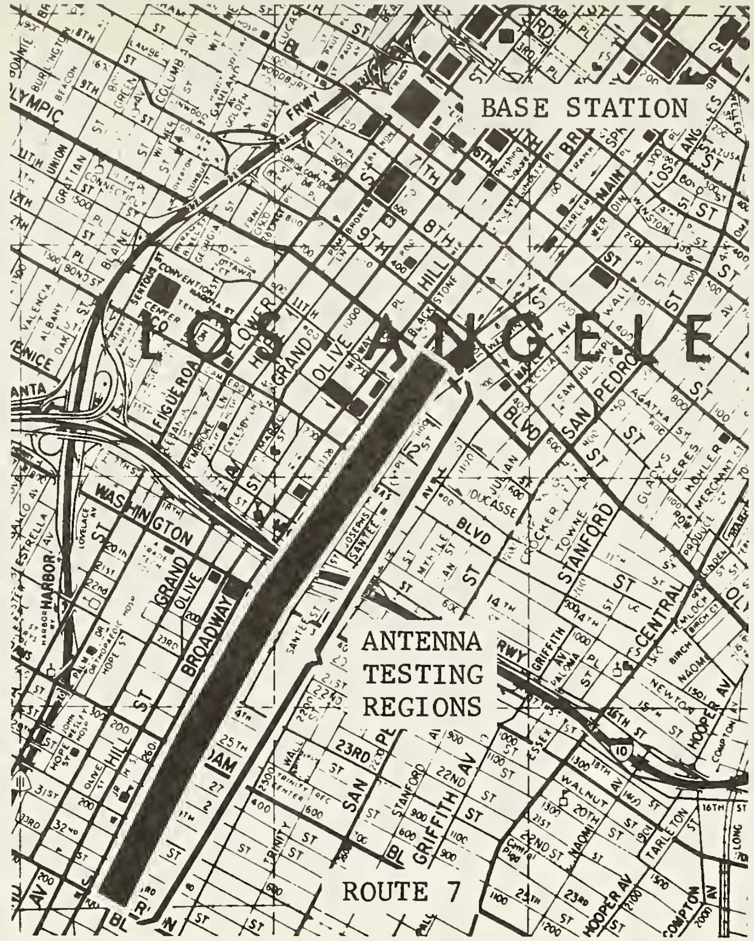


FIGURE 4-9 ANTENNA POLARIZATION TEST RESULTS

how peak fades were effected when (1) two vertically polarized and (2) circularly polarized antennas were used. It was, therefore, concluded that both were essentially comparable in their individual performance at the 800 MHz frequency.

4.8 Baud Rates

The effect of varying the baud rates on the throughput and coverage was studied by performing tests of baud rates of 1000, 1500, and 1800. The overall throughput over Route 7 was determined to be 93 percent, 92 percent, and 89 percent respectively at 1000, 1500, and 1800 baud. These tests were conducted with the UCB building as a base station; the polarization of both the base and mobile antennas was vertical and a polling rate of one poll every 50 feet was used.

4.9 Overall Coverage of the Different Routes

The two base station sites that were used to examine the throughput achievable on the different routes exhibited the throughput values presented in Table 4-1.

4.10 Comparing Results With Model Predictions

The results obtained were compared with the predictions of a modified model developed by Reudink (Reference 3). The average signal strength observed in the following areas with the UCB Building as the base station were used:

- Santa Monica
- Eagle Rock
- Beverly Hills
- Downtown Los Angeles
- Compton

The primary reason for using the model discussed by Reudink and based on Okumura's (Reference 3) findings, was that factors such as terrain

TABLE 4-1 COVERAGE FROM UCB BUILDING

Route	Overall Percent Throughput	Problem Areas
2	97	None
7	92	Eagle Rock Area
26	96	One 500 foot segment on Atlantic Avenue was approximately 65 percent.
29	97	On Compton Blvd, between Central and Avalon, two 500 foot segments were approximately 65 percent.
65	78.4	Back of Dodger Stadium near Ridgeline was approximately 35 percent.
83	74	Progressively worse towards Santa Monica to approximately 20 percent
142	93	Two 500 foot segments and one 3500 foot segment along Hazard Street
	COVERAGE FROM KJOI	
29	81	Distributed over whole route
65	65	Back of Dodger Stadium near Ridgeline
83	86	Primarily between Oakhurst and Rosemore
89	65	Distributed over whole route.
	COVERAGE FROM VERDUGO PEAK	
7	79	Eagle Rock Area
	COVERAGE FROM FLINT PEAK	
7	78	Route segments along Colorado Blvd, in back of Mt. Washington, and downtown Los Angeles.
26	64	Distributed over route.
41	82	Distributed over route.
83, EC9-14	78	Distributed over segment.

correction, propagation loss, and antenna height gains are based on empirical data. The model was modified to include a fast fade-factor and put into a tabulated form of system gains and losses with the resultant being an overall system margin. Computation of the overall system margin involves the following steps:

1. Determine the free space propagation loss for the path between the base station site and each area, using the equation $(\lambda/4\pi D)^2$ where λ is the wave length at 850 MHz and D is the distance between the base station and the subject area.
2. Determine the coax and VSWR loss. The coax loss allotted for the vehicle antenna was based on 25 feet of RF/58 at 850 MHz. This was 2 dB. The VSWR loss allowed for the vehicle antenna was 0.5 dB. The coax loss allowed for the base station antenna based on 100 feet of 7/8 inch Heliax was 1.5 dB. The VSWR loss for the base station antenna was neglected. Therefore, the combined coax and VSWR losses were 4 dB.
3. Determine the urban area median attenuation factor. Using the distance between the base station and the subject area, and the frequency of operation, this factor can be read off directly from Figure 4-10.
4. Determine the base station antenna height gain factor. Knowing that the height of the antenna at the base station is about 375 meters, and using the distance between the base station and the subject area, this factor can be read off Figure 4-11.
5. Determine the suburban correction factor. This factor can be read off directly from Figure 4-12.
6. Determine the Excess Reverse Slope factor. Using the slope of the terrain appropriate for the Region, this correction factor

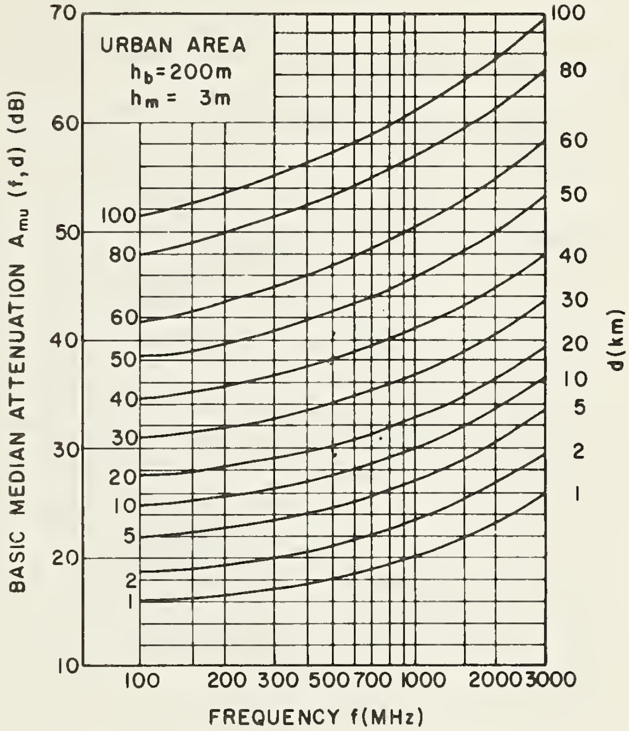


FIGURE 4-10 PREDICTION CURVE FOR BASIC MEDIAN ATTENUATION RELATIVE TO FREE SPACE IN URBAN AREA OVER QUASI-SMOOTH TERRAIN

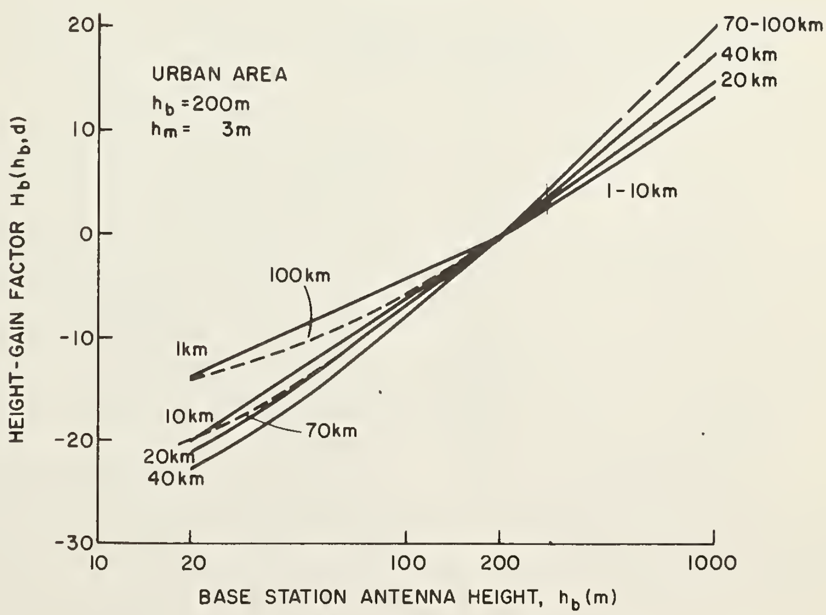


FIGURE 4-11 PREDICTION CURES FOR BASE HEIGHT GAIN FACTOR

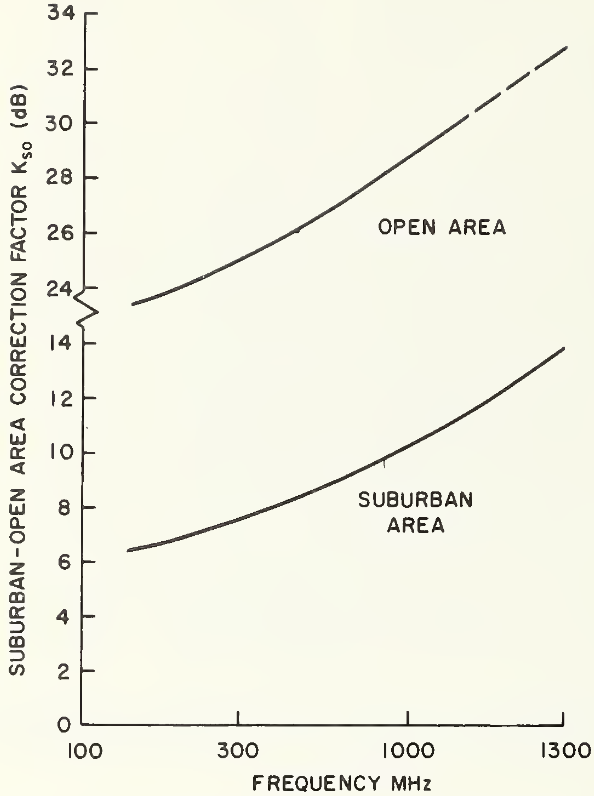


FIGURE 4-12 PREDICTION CURVES FOR SUBURBAN AND OPEN AREA CORRECTION FACTOR

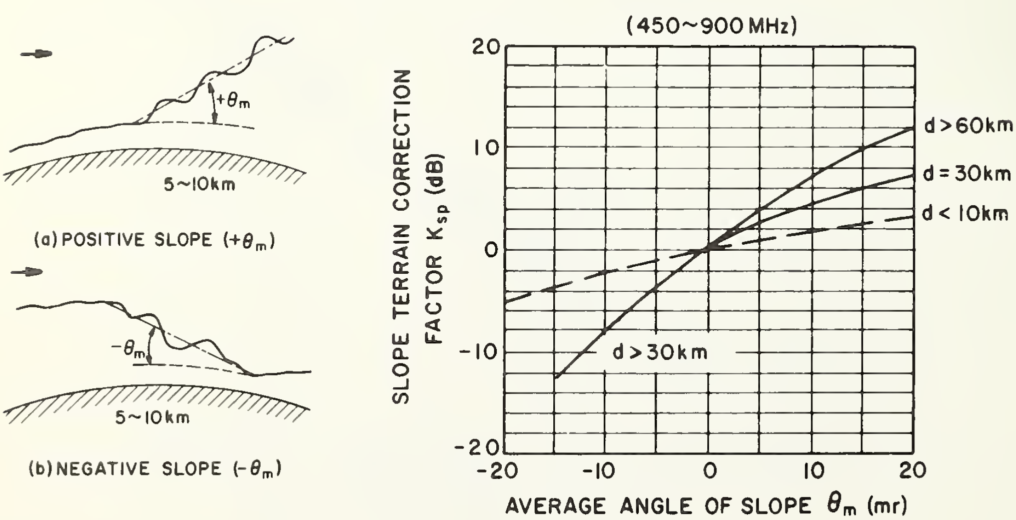


FIGURE 4-13 MEASURED VALUED AND PREDICTION CURVES FOR "SLOPE TERRAIN CORRECTION FACTOR"

can be determined from Figure 4-13.

7. Determine the terrain modulation factor using the hilly terrain appropriate to the path between the base station and each region from Figure 4-14.

8. The fade margin factor at the 95 percent level is assumed to be 25 dB for 850 MHz.

9. Determine the transmitter power gain. This is obtained by converting the transmitter power of 35 watts to dB.

10. The transmitter and receiver antenna gain is obtained from the antenna specifications.

11. Determine the effective receiver sensitivity gain. The specified sensitivity for most 850 MHz mobile radio receivers is $0.35 \mu V$ for 12 dB SINAD. This signal level of $0.35 \mu V$ corresponds to a receiver input signal power of -146 dBW. This is the figure used for the effective receiver sensitivity gain.

12. A final summation of all the gains and losses for each area yields the overall predicted margin that the instantaneous signal strength will not fall below 12 dB SINAD 95% of the time for a message length of 150m seconds.

The results of this process are contained in Table 4-2.

Two factors need to be considered to alter the model for the purpose of predicting average signal level for comparison with measured signal level data. These alterations yield the basic model described by Reudink (Reference 3).

- Since we are concerned only with average signal strength, the fade margin at 95 percent, namely 25 dB, was deleted from consideration. This means that 25 dB needs to be added to the overall system margin.

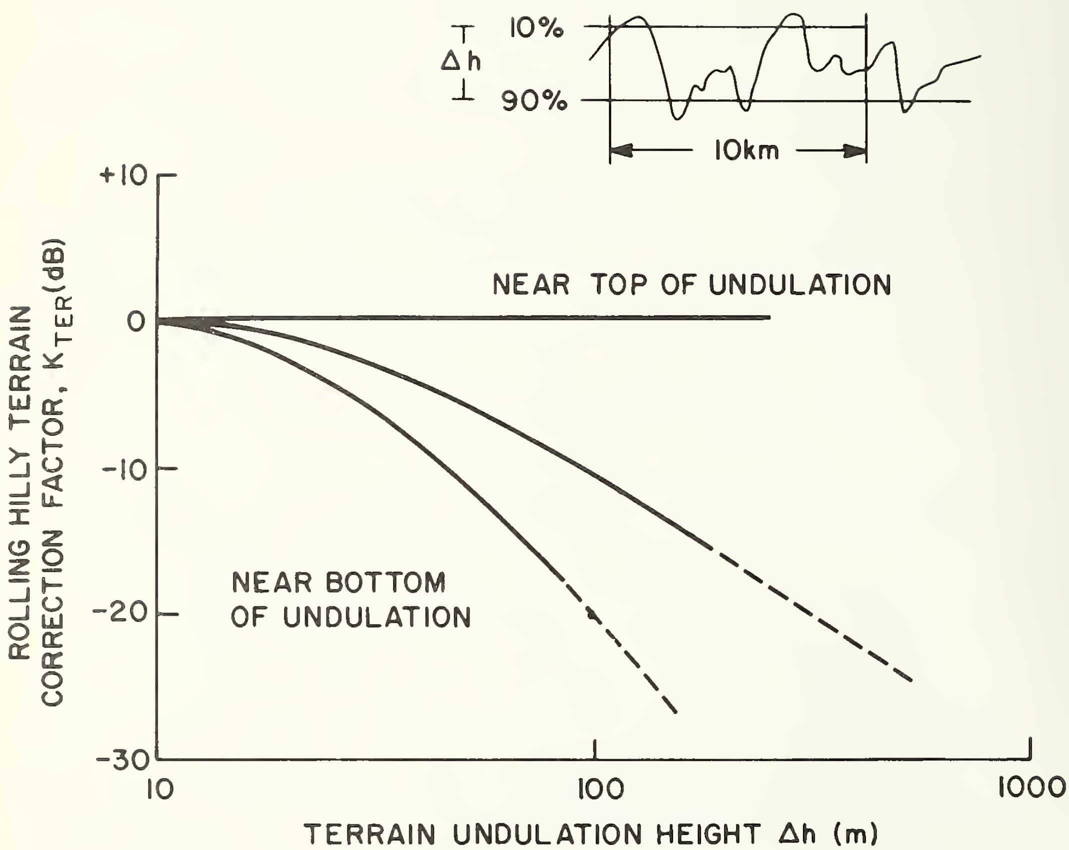


FIGURE 4-14 ROLLING HILLY TERRAIN CORRECTION FACTOR

TABLE 4-2 AREA GAIN AND LOSSES

UCB	Range Km	Coax & VSWR Loss	Propagation Loss Free Space	Urban Area Attenuation Factor	Base Station Antenna Height Factor	Suburban Correction Factor	Excess Reverse Slope Factor	Terrain Undulation Factor	Fade Margin Factor 95%	Xmit Power Gain	Xmit & Rec. Ant. Gain	Effective Rec. Sens. Gain	Margin	Signal Strength
1. Santa Monica	2.31	-4	-118	-33	+3	+9	-10	-10	-25	+15.4	+7.5	+146	-9.1	(-9.1+25-116)=-100.1
2. Eagle Rock	9.6	-4	-111	-28	+3	+9	-5	-20	-25	+15.4	+7.5	+146	-11.2	(-11.2+25-116)=-102.2
3. Beverly Hills	12.8	-4	-113	-30	+3	+9	-3	-17	-25	+15.4	+7.5	+146	-11.1	(-11.1+25-116)=-102.1
4. Downtown LA	1.6	-4	-95	-22	+3	0	0	-5	-25	+15.4	+7.5	+146	+20.9	(+20.9+25-116)=-70.1
5. Compton	17.6	-4	-120	-35	+3	+9	0	0	-25	+15.4	+7.5	+146	-3.1	(-3.1+25-116)=-94.1

TABLE 4-2 (CONTINUED)

UCB	Signal Strength W/O Terrain Undulation Factor	Actual Signal Strength
1. Santa Monica	-90.1	-93.8
2. Eagle Rock	-82.2	-92.5
3. Beverly Hills	-85.1	-87.8
4. Downtown LA	-65.1	-70.2
5. Compton	-96.1	-68.0

- To convert the overall system margin to dBm, since the system was constructed with signal strength referenced to 12 dB SINAD, -116 dB needs to be added to the margin that appears in the last column.

Thus, with the base station at the UCB Building, the predicted average signal strength for each of the areas is as follows:

Santa Monica	-100.1 dBm
Eagle Rock	-102.2 dBm
Beverly Hills	-102.1 dBm
Downtown Los Angeles	- 70.1 dBm
Compton	- 94.1 dBm

It can be seen from Figure 4-15 that the model as it stands tends to under estimate the average signal strength.

When the terrain undulation factor is deleted from consideration in the calculation of the average signal strength, the errors of prediction show a tendency to reduce in magnitude (two out of the five cases), but the model then shows a bias towards overestimating the average signal strength. Since the effects of terrain undulation on the propagation of electromagnetic energy are so complex, predicting a loss factor for these effects is at best an estimate. Depending on the exact nature of the terrain, the estimated loss due to this factor may be high or low. It appears that halving the estimated terrain undulation loss factor would have provided a reasonably close correlation between predicted and measured average signal strengths for all areas considered except Compton. The average signal strength model underestimates the actual signal strength by approximately 20 dB. The most likely cause of this discrepancy is the value used to estimate the urban area attenuation factor. The terrain in the Compton area is flat and no ridgelines or

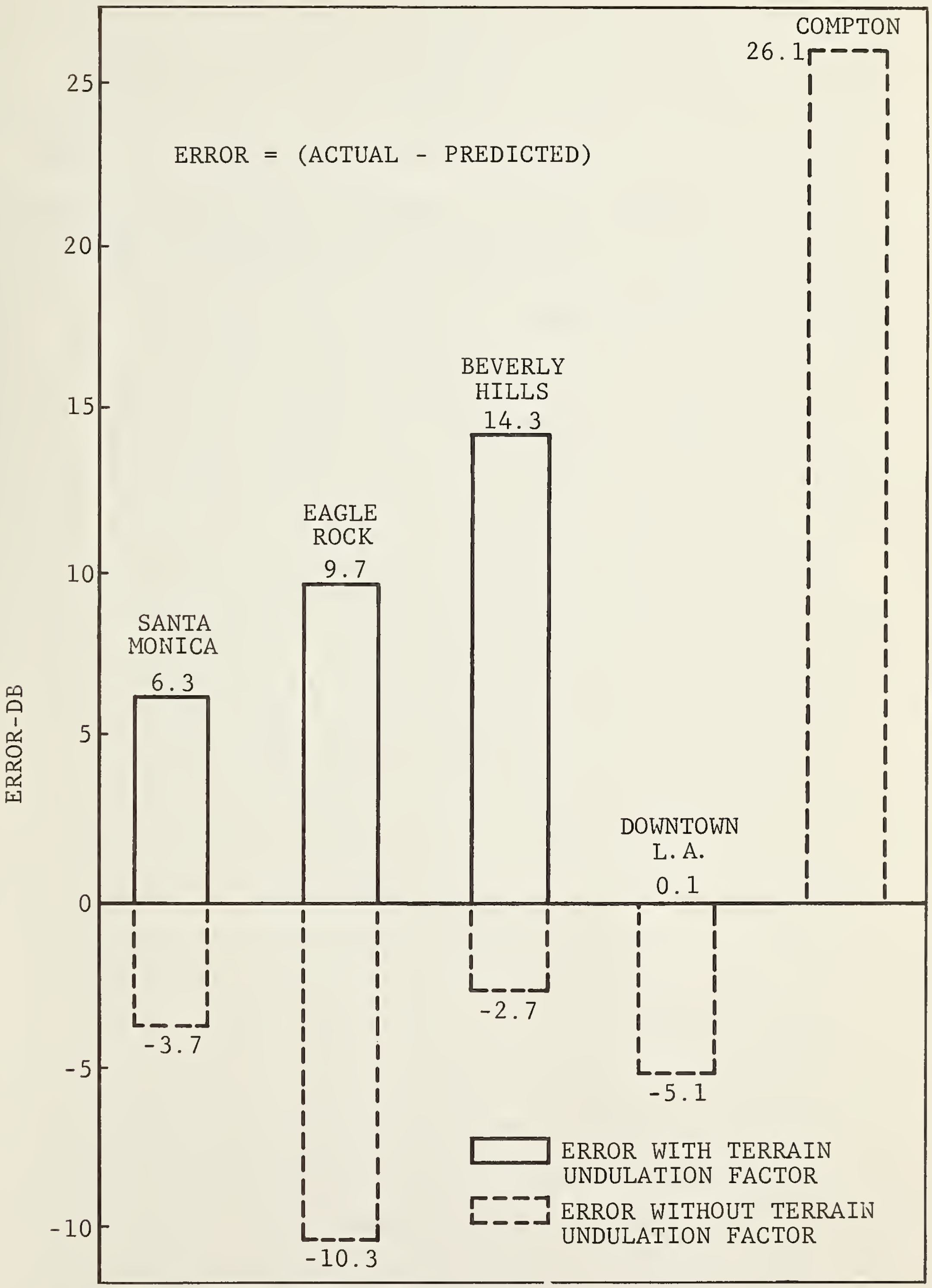


FIGURE 4-15 ERROR IN PREDICTION OF SIGNAL STRENGTH

other topographical features are present between the UCB Building and Compton. The urban area attenuation factor presented by Reudink, based on the work of Okumura (Reference 3), was a result of a number of measurements over various types of terrain and represents an average. The physical situation that exists between the UCB Building and Compton indicates it is one of the more ideal coverage situations that one may encounter from time to time.

SECTION 5

CONCLUSIONS

The results of the 800 MHz Survey indicate the following:

1. Multiple base stations will be required to provide the specified coverage of the six selected SCRTD bus routes. The primary reasons for multiple base stations being required is the effect the fast fades have on the transmission of digital data and the influence of the terrain factor observed in Los Angeles. The effects of the fast fades require that the system exhibit an additional 25 dB margin to meet the 95 percent overall throughput and 75 percent throughput on any 0.1 mile segment. Originally, a 15 dB margin was thought to be sufficient, based on predictions from the literature; however, the test results reported herein show that indeed a 25 dB margin is necessary.
2. The results indicate that the use of a circularly polarized (CP) antenna system does not reduce the effects of fast fades compared to a vertically polarized antenna system. The primary reason for this test result is probably due to the fact that the instantaneous signal received at any point is composed of a number of individual signals that have arrived at that point by a number of different paths. Only seldom is there clear line of sight between both transmit and receive antenna in a land-mobile environment. Therefore, most of the time the energy being received is reflected energy. Since the sense of a CP wave reverses to a degree each time it is reflected, the probability of the waves being correctly polarized when impinging

upon the receive antenna is low.

3. Baud rates between 1000 and 1800 BPS can be used effectively for the transmission of digital data using commercial 800 MHz mobile radios presently on the market. However, the higher the baud rate, the more closely must be controlled the phase and amplitude response of the radio's audio conditioning circuitry between the MIC input and the modulator, assuming a direct tie-in to the modulator is not available. Mobile radios specifically designed for data transmission would simplify this problem and allow higher data rates. However, since message lengths in this type of system are on the order of a hundred milliseconds, the attack time and turn off times rapidly become more significant in determining overall "burst" data throughput than baud rates.
4. When compared to data transmission coverage at UHF frequencies in the 400-500 MHz range, the coverage obtained at frequencies in the 800 MHz range appears to be 2-5 percent worse. This difference is expected since the free space propagation loss is higher at 800 MHz and the number of fast fades that occur will be more numerous since the wave length is shorter. Coax losses are somewhat higher at 800 MHz compared to 450 MHz and antenna efficiencies are lower.
5. Signal fade levels observed during the tests at 800 MHz were on the order of 25 dB at the 95 percent point independent of the terrain. This fade level observed was probably influenced by the finite sampling resolution of the measuring system but is probably a reasonable indication of the fast-fade factor that must be considered in a land-mobile data transmission system operating in the 800 MHz band. This factor and the

signal level margin that must be allowed for it reduces the effective area that can be covered by a given base station.

SECTION 6

REFERENCES

1. Gould Information Identification Inc., "Test Plan for 800 MHz Communication Survey in the Los Angeles Area," DOT-TSC-1237.

2. Jakes, W. C., Jr., "Microwave Mobile Communications," New York: Wiley, 1974, Chapter 2.

3. Ibid. p. 92-128.

APPENDIX

REPORT OF NEW TECHNOLOGY

The work performed under this contract during the evaluation reported herein has led to no new inventions. The circularly polarized antenna design used for field measurements is based on well-established basic antenna design fundamentals and represents no new technology.

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